MICROPEDOLOGY

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To My Collaborators
and Students

FOREWORD

With some changes and additions, this book represents the lectures which the author, as a guest professor at Iowa State College in Ames, has given in several courses to graduate students during the spring, summer and fall quarters of 1937. In it the writer has attempted to give to the English reader a summary of the methods and the results which he has obtained in close collaboration with his co-workers in the field of microscopic pedology (micropedology). Some methods which have been developed in other natural sciences have been found to be indispensable in soil microscopy. Accordingly, these have been described, but since many of them, such as, for example, the use of the polarizing microscope or the general technique of microchemistry are given at length in numerous textbooks, only essential details are included here.

As lectures to graduate students the presentation of the subject is based upon a general knowledge of pedology, soil microbiology and the principles of microscopy.

As a part of general pedology, micropedology deals with the morphology, genesis, general dynamics and biology of soils. Soil mineralogy, as a counterpart of micropedology, deals with the independent study of the soil minerals, especially the so-called clay minerals. Both branches, though primarily united by the application of microscopic methods, relate to each other as general mineralogy relates to petrography and petrology. Soil mineralogy is, therefore, an ancillary science and not a part of micropedology. There are many unsolved problems in both fields, the solution of which will consume lifetimes of effort.

This book is devoted to the fundamental principles of microscopic pedology. The importance of its application in the different branches of practical soil science, especially in the fields of soil erosion, soil mapping, agricultural soil classification, tillage, engineering and road construction, will be the subject of separate publications to follow.

A noted geographer once said: "It is safe to say that for the majority of mankind the superiority of geography over geometry lies in the appeal of its figures." The author thinks that the increasing popularity of microscopic pedology with the public

as well as with the student is due primarily to the appeal of the wealth of interesting formations and happenings which can be observed in the microscopic world of the soil. To the student who has been accustomed to see and to experience nature only three-dimensionally in his own macroscopic dimensions, the microscopic cavities and the life in them appear as they would were he actually standing or walking in them. Like the explorer in exotic parts of the earth he roves through the endless systems of ravines and chasms, always eager for new impressions and new discoveries. They always come, because there is much left for everybody to study, describe and explain.

It is a great satisfaction for an author and investigator to have followers and collaborators who take part in his work with the same feeling and pleasure and the same understanding of the significance of every small step forward that is made. The writer wants to express his deep appreciation to all who joined him on his way. There is, furthermore, no better occasion than the publication of these lectures to remember the students who have listened to them and who have worked for some time on different soil problems in the author's laboratory. In remembrance of the pleasant hours of mutual planning and working, the author dedicates this book to his students and collaborators.

Microscopy is still only sporadically used by the soil scientist. In view of the great potentialities of its application it is desirable that students of as many institutions as possible should get a thorough training in the general methods of soil microscopy. Since personal teaching and instruction is the best and quickest way, the author intends always to devote a part of his time to the training of research students in the field of microscopic pedology.

The author is indebted to Dr. R. E. Buchanan, Dean of the Graduate College and Director of the Agricultural Experiment Station in Ames, for the invitation to lecture at Iowa State College, and for many helpful suggestions in regard to the writing of this book. He is indebted to the late Dr. P. E. Brown for his kind help in facilitating the author's work at Iowa State College and the preparation of this book in its earlier stages. The book is written in the language the author used in his lectures. The writer is indebted to his colleagues, especially Dr. A. G. Norman and Dr. J. B. Peterson of Iowa State College and Howard J. Horn of the University of British Columbia in Vancouver, for the elimination of grammatical errors and many suggestions to purify the text from unusual constructions. Acknowledge-

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Most of the microphotographs have been prepared by collaborators of the writer with the Czerny attachment camera of C. Reichert. The pictures of thin sections have been taken with the microattachment camera of C. Zeiss. The great majority of the drawings were made by Miss Marguerite Root in Ames and a few by the author. Special acknowledgement must be made of the great assistance given by the Collegiate Press and Professor Blair Converse, Head of the Department of Technical Journalism at Iowa State College.

W. L. Kubiëna

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INTRODUCTION

Pedology as an independent science should be the basis of agricultural soil science just as geology as an independent science is the basis of mining. However, practical soil science developed its principles almost entirely from the experiences of practical farming without the background of a thoroughly developed natural science.

Pedology as a natural science is still in the first stages of its development. But it is also in the first stages of the recognition of its necessity by the agriculturist. While pedological discussions become almost a fashion among the geographers, plant sociologists, and sedimentary petrographers, especially of the European countries, still not enough is done for the promotion of this young science by those who will most benefit by it.

No fundamental work is useless. No one thinks it useless that those who are doing research work concerning the human body are always busy in attempting to arrive at an understanding of the slightest details of its function and in searching for the slightest details of its microscopic structure. Thorough knowledge and real understanding of a formation in nature as a whole and in all its possible details is still the quickest way to meet all difficulties arising in cases when its functions turn to be injurious, or to find new means to influence its processes in the most profitable way.

Fundamental work, however, is most important and necessary where we know as few facts about a formation in nature as we do in the case of the soil. Pedology as a natural science, after a promising start, still is developing slowly. We are not much further with pedology in its present stage than we were with petrography in the middle of the last century. At that time the predominating lines of study were descriptions of rock profiles or pieces of rocks, the first trials of genetical interpretations based on these descriptions, and the beginning of a chemical analysis. Very little was known about the rock components.

At the end of the sixth decade of the last century petrography experienced a remarkable stimulus to its development by the introduction of microscopic methods in the investigation of rocks. Thin section petrography became so important that there

is no petrographer today who can claim to progress without intensive use of the microscope. The nature, morphology, and arrangement of the constituents in the rocks brought about a real knowledge of the genesis, movements, and functions of the single ingredients in the whole mass, and a more thorough understanding of the appearance and past physiology of the formation in its entirety. Furthermore, it became possible to verify and interpret satisfactorily the results of chemical investigations. It is easy for anyone familiar with micropedological investigations and their tremendous possibilities in providing information on soil morphology and soil dynamics to predict that there will be a time in the future when no pedologist can be without the use of the microscope.

Just as microscopic petrography did not develop into a special branch of petrography performed only by specialized investigators, so micropedological investigations will be as little confined to a special phase of pedology. In this sense the author did not intend to create a new branch of science when he first used the term micropedology about eight years ago. Similar to thin section petrography it will remain a special branch only so long as the recognition of the possibilities and necessities of the use of microtechnique in pedology does not become common to all. Some interpretations designated in this book may change, the methods will be perfected; the idea, however, will remain. If it dies, it would have to be created once more in the further development of general pedology.

CHAPTER I

The Principle of Micropedology

What is micropedology? What use has it in general pedology, and how do its principles differ from the latter?

The first question which natural science generally asks in opening a new investigation of an object in nature is: How does it appear? If we would state this question more exactly, we would have to say: How does it seem to us? How does it seem to our special human senses? Because, as the philosophers tell us, we know nothing about the things as such, we only know how they seem to us.

How does the soil appear to human beings? It looks like a more or less plastic mass, in most cases somewhat drab in color and possesses certain physical and chemical properties.

If we were of the size and if we had the manner of living of the microorganisms, our answer would be quite a different one. Perhaps we would say: The soil is a huge system of many-shaped cavities, which are built of glassy material, partially clear and colorless, partially intense green, red, yellow or brown, almost entirely transparent, seldom translucent and only infrequently opaque. In the cavities active organisms are to be found; in some only few, in others very many, according to the size, climate, and food condition of the various cavities.

For centuries science in general advanced knowing little of matter save what man could observe under ordinary conditions. Since the construction of microscopes and other instruments, man has been able to penetrate deeper, to see and to know more. But this "knowing more" developed only through accident, and still the things are perceived not as they really are, but only as they appear to us, for knowledge depends very much on the instruments and the methods which are available to us. Through the use of improved instruments, or instruments which work in another way, and better methods, it has been shown that many concepts developed through use of older instruments and methods have led us to false conclusions. We shall always continue to have new and improved instruments and better methods in the future.

Did we not use the microscope for soil investigation in the past? It was used primarily for examining soil microorganisms or for determining mineral particles by optical methods developed by petrographers. It was used for the investigation of a small group of soil constituents, isolated from the soil, and not for the investigation of the soil itself as a formation and as an entity. We were able to isolate a few ingredients of the soil and to work with them in isolated stages, but we knew very little about how these ingredients were related in the soil, in what microscopic location they were to be found, how they arrived at these places, and what role they played in their environment. Since many objects occurring in the soil spaces are so fragile that they are destroyed by the least disturbance, our knowledge of them was negligible.

Take, for instance, the city of New York. If it were put in a large glass vessel with water or hydrochloric acid, as we do with the soil, and shaken for twenty-four hours, one would not then be able to reconstruct Broadway, Fifth Avenue, or the Empire State Building, or to find out what kind of goods are found in the large warehouses on the New York harbor. The first thing to know, in order to get an idea of New York, is not so much the nature of its chemical composition as a whole, but how it looks in detail as a structural entity.

This is not to be read as a criticism of the existing methods and procedures of soil research. They will find their use in the future as they have in the past, but they need amendment. In microscopic dimensions the soil is not just a mass, but a whole world. We are able to get an idea of what we know of this world if we think of it in terms of our world translated down to microscopic dimensions. All its towns, villages, houses, church towers, trees, men, and animals would be visible only by the use of a good microscope. We could not have known very much about it if we had not lived in it ourselves. It would appear to us as does the soil, quite like a mass. Naturally then we cannot treat this soil world *en masse* if we wish to know what is actually going on within it.

What principles have we to observe in investigating the microscopic world of the soil? First of all the soil must not be disturbed in its natural arrangement. The spaces must be opened but not destroyed. How can this be done? Generally we split open the undisturbed soil sample with a strong needle or we break it open. Now we take some single soil spaces and try to translate all these unimaginable small objects into the more

familiar dimensions of our own world. We have to use special microscopes for this purpose which work, not with transmitted light, but with incident light. They enable us to investigate formations in nature directly without the necessity of making special preparations. They allow an observation of things in nature *in vivo* and *in situ*.

Microscopes employing reflected vertical light have found extensive use in metal microscopy, but in metal microscopy the preparations have plane and polished surfaces. In soil microscopy we examine cavities, many of which are comparatively deep. This prevents us from the free use of the highest magnifications, and in part also from the use of the so-called vertical illuminators.

We need, furthermore, not only to see the microscopic objects and organisms in the undisturbed soil, but also to handle everything to be found in the soil spaces, to take things out, to put others in, to investigate some of the constituent substances chemically and physically, to carry out measurements in a selected region, and to arrange experiments in small cavities. The possibilities for doing all this are disclosed to us by methods which in their totality we designate as "microtechnical methods." The term "microtechnique" or "microtechnical methods" is used here in the sense of methods which have to be performed in microscopic dimensions. They are always confined to the use of the microscope, and that not only for mere observation or temporary control of the effect of manipulations, but for the actual performance of these manipulations. Methods of this character which are used in micropedology can be divided into three groups: (1) micrurgical methods, (2) microchemical methods, and (3) microphysical methods. The name of the first group is derived from micrurgy, which means the art of manipulating microscopic objects. The term is used here in a somewhat wider sense, i. e., not only for manipulations performed by using the highest magnifications, special manipulation apparatus and finest glass tools, but for every kind of manipulation performed with the aid of a microscope. Micropedological work needs, for the great part, methods of a kind of semi-micrurgy, using lower magnification, incident light, free hand manipulation, and resterilizable metal tools.

In view of the particular necessity for the use of microtechnical methods in micropedological research it is essential to know what similar methods have been developed by other sciences, how these methods may be used for soil investigations,

how they may be adapted to this purpose and what other methods, not yet developed, remain to be devised as parts of the technique necessary to achieve our aim.

CHAPTER II

Use and Development of Microtechnique in Other Natural Sciences

The possibility of doing research work by methods performed in the world of microsopic dimensions has always been available to us from the very beginning of the use of the microscope. Yet the real development of microtechnique in its various fields has occurred only within recent decades.

One disadvantage in the development of microtechniques, although an advantage for the development of microscopy in general, was the development of the microscope itself. The first microscopes were incident light microscopes and were used on the living or undestroyed objects in nature. However, the microscope soon became a transmitted light microscope and reached a high peak of development in magnification as well as in illumination of the picture. Transmitted light microscopy involves the necessity of preliminary preparation of natural objects. Only very recently has incident light microscopy regained interest, not only in the field of metal and ore investigation, where it reached a high development long ago, but also in biology. Accordingly, in Switzerland, Paul Vonwiller has particularly favored incident light microscopy in animal histology and physiology, because it alone permits of an investigation of the living object.

His requirements were to obtain true-life pictures, to observe life instead of being forced only to reconstruct life from preparations. Vonwiller, in the earlier stages of his work, used mainly opaque illuminators in connection with the micromanipulator of Péterfi.

These researches and those made by a number of investigators in other fields have led to new developments in the manufacture of instruments for incident light microscopy.

When it was stated that microtechnique developed only very recently it was not meant that there were no micromanipulations performed previously. Attempts to manipulate under the objective of a microscope date as far back as the use of the

microscope itself, but there were only occasional attempts and did not at the time contribute to the establishment of a thoroughly developed technique of investigation. Apparently, de Saussure in 1815, was the first who tried staining reactions for the determination of the chemical nature of microscopic quantities of substances. In 1859, H. D. Schmidt constructed the first micromanipulator with a screw movement. However, the construction was such that the apparatus could be used only with lower magnifications, and since the trained hand generally works more easily, rapidly and individually than an apparatus, it found no special attention and application.

Though the methods for the preparation of thin sections of rocks are not microtechnical methods according to the definition given at the end of the previous chapter, their importance to the subject of this book is so great that they should be mentioned at this place. It seems that W. Nicol, in 1827, was the first to have the idea of preparing thin plates of minerals. In 1831, studies of thin sections of labradorites were published by Nordenskiöld. The method in general use today, however, was worked out by H. C. Sorby in 1859. Its general application originated from the important contributions of F. Zirkel (1863), Vogelsang (1870), K. Rosenbusch, G. Tschermak and A. Michel-Lévy. It is of particular interest that a parallel development of soil microscopy was claimed by de Gasparin (1863) at almost the same time.

Of special value for direct investigations in the microscopic world was the development of microchemistry. We find that Teichmann from 1853 to 1857 had already worked on the production of haemin or chlorohaematin crystals for the determination of blood, by which method very small quantities of blood could be detected. The real founder of microchemistry as a branch of science was the Dutchman, W. Behrens. In the year 1870 the mineralogist, F. Zirkel, in Berlin called Behrens' attention to the advantage of the determination of the mineral particles in thin sections of rocks by placing acids on their surfaces, allowing them to dry, and observing the resulting chemical changes of the different ingredients. Behrens stated that it was through this communication that Zirkel brought to him the idea of microchemistry. Behrens worked on his idea quite privately and did not publish until 1882, in which year appeared the first edition of his book "Mikrochemische Analyse," a collection of his methods. In the meantime the mineralogist, Bořický, in Prague, published in 1877 a paper with

the title "Elemente einer neuen chemisch-mikroskopischen Mineral-und Gesteinsanalyse." The publication contained methods for the microscopic determination of some cations in the form of fluorides. These methods persisted for many years in the textbooks on analysis of minerals in rocks, although the fluorides are not very useful in this case. Behrens' methods were suited to general application because he used especially the sulfates instead of the fluorides. It may be mentioned that before Bořický, Wormley, 1867 in the United States, wrote a paper on the microchemistry of poisons.

Botanical microchemistry was originated at about the same time, although a long time elapsed before this important branch found general acceptance. The first botanical microchemistry was written in 1883 by Paulsen. In 1883, some contributions were made by W. Behrens, and in 1891 the Viennese, Hans Molisch, published his book, "Pflanzliche Histochemie," which was the beginning of the later important handbook, "Die Mikrochemie der Pflanze." Another important textbook was written in 1913 by Tunmann ("Pflanzenchemie") which was continued later by Rosenthaler.

The development of microchemistry brought to botany immense advantages, especially in anatomy and physiology. Only by microchemical methods did it become possible to observe and to study the formation, disappearance, change, storage, and distribution of the different chemical compounds in the cells and tissues. These methods alone were able to show the most delicate and intimate details of the cell life and, furthermore, the function of the different cells in the plant as a whole. Compounds present only in quantities of a few γ ($1\ \gamma = 1$ millionth of a gram) can be determined.

Not only in botany but also in the histochemistry and physiological chemistry of animals did microchemistry become widely used. The difficulties here are much greater than in botany, where the great resistance of the cellulose membranes allows the application of stronger solvents. Animal tissues are almost entirely destroyed even by dilute acids. Furthermore, in the plants simple organic compounds and mineral substances occur much more frequently. Special difficulties arise in physiological microchemistry of animal tissues. The structures are apt to be entirely destroyed and localization of the substances can be obtained only indirectly. Up to the present, with some exceptions, conclusions could be made only by the morpho-

logical picture of preparations, in which life, the principle thing, is absent.

Great possibilities were opened for microtechnique in general by the recent development of micrurgy. This term, which was created by Péterfi in Berlin, means the performance of micromanipulations even under the highest magnifications by means of highly developed instruments, the so-called micromanipulators, and by means of very fine glass tools.

It was mentioned that the first attempt to construct a micromanipulator was made in 1859 by H. D. Schmidt. After a long period, another attempt was made in 1895 by Herlitzen, but this apparatus also found no special application. In 1909 Schouten started a new period of successful attempts in constructing new models as well as in their application. The first to construct a manipulator which could meet all requirements was M. H. Barber in America. He published in 1914 a paper on the well known Barber pipette, a micropipette with a fine screw movement which can be fixed on the stage of the microscope. The use of the Barber pipette was developed into a useful technique, especially by Kite and Chambers. Micromanipulators were constructed after this first successful attempt by many investigators and reached their perfection in the apparatus of Chambers in New York, made by Leitz, and the manipulator of Péterfi, in Berlin, made by Zeiss.

Micromanipulators found a wide distribution and allowed manipulations and investigations in their application to histology, cytology, embryology, microbiology, etc., which opened almost fantastic possibilities.

The potentialities of the application of microtechnical methods to pedology and soil microbiology become obvious immediately if one considers the contribution made by similar methods in petrography as the next related science, or in botany and animal histology as biological sciences, and the very needs of both soil microbiology and pedology. With regard to the needs of soil microbiology some lines of S. A. Waksman's book, "Principles of Soil Microbiology," may be cited: "We possess at present considerable information concerning the organisms (of the soil). . . .under controlled laboratory conditions; but little is known of the processes carried on in the soil itself, by numerous representatives of the soil flora and fauna."

In another place, stating the most outstanding problems of soil microbiology, we find ranged as the first problem the necessity of : "microscopic and cultural methods in soil micro-

biology, especially those which tend to indicate the conditions active in the soil (under field conditions) and their role in the transformations taking place in the soil."

In regard to pedology we need only to look at the development of the research methods in petrography. Quite similar to the pedologist the petrographer begins his investigations with the field work, but then his most important laboratory work is the microscopic investigation on the nature and morphology of the ingredients of the rocks and the particular way in which they are combined in the whole. The second part is today the most important of all investigations in petrography. Finally the chemical analysis of the whole is carried out as a kind of summary determination.

In pedology today we start with the field work. The second part, the investigation of the microscopic ingredients, their nature, morphology, role, and the way they are combined to the whole is entirely omitted. We are performing only the third part, the chemical analysis of the whole.

Let us examine the prospects for the application of microtechnical methods worked out in other natural sciences to investigations on the morphology, chemistry, microbiology, and dynamics of soils.

At first we see some advantage. If we cut a soil, we do not cut an individual organism like an animal or plant. The organisms within the soils remain undestroyed; in most cases they even continue their life activity. Generally also there are no displacements of substances. Except for a few cases we are able to obtain undisturbed microprofiles by splitting or breaking selected parts of the soil.

In view of all the experience gained in other natural sciences, the work we have before us is much facilitated. We possess a large number of micromethods which enable us to determine microchemically and optically almost every inorganic and organic compound likely to be met with in the soil. The difficulties arising in soil microbiology which will be mentioned later are for the most part only of minor importance. The only trying circumstance which delays a general use is that investigators of soil microbiology and pedology are not accustomed to performing microtechnical work. The slight effort expended in becoming familiar with microtools and micromethods is worth the new possibilities in research. It will be a great satisfaction to everyone who attempts micropedological investigations to find that pedology and soil microbiology become the

most interesting, lively, and fascinating natural sciences.

Microtechnical methods were not applied to soil investigations until attempted by those developing micropedological work. The different newer methods in soil microbiology, however, originated by Conn in 1918, by Rossi in 1927, by Winogradsky in 1928, by Koffman in 1929, and by Cholodny in 1930 show, obviously, the development in the direction of micro-investigations *in situ*. Microtechnical methods will allow us to take the final step. They will make possible not only investigations *in situ* but both *in situ* and *in vivo*.

Part II
THE TECHNIQUE OF MICROPEDOLOGY

CHAPTER I

Incident Light Microscopes

Micropedology requires above all the use of incident light microscopes because it is necessary to examine the opaque soils in an undisturbed condition. A crushed or pulverized soil is related to the soil formed by nature like a pile of debris to a demolished building. Anyone who knows what an abundance of details regarding formation can be given by an undisturbed soil will hardly believe that we formerly stored pulverized soil samples for exhibition or later investigation. If someone intends to exhibit pulverized soil specimens in a soil museum, he should reflect that it is not customary to exhibit rocks, wood specimens, snails, or crocodiles in a pulverized state in such a museum.

The manufacture of incident light microscopes has developed rapidly very recently and we still obtain new modifications and new apparatus every year, brought out by the different optical factories.

They are either common microscopes supplied with auxiliary illumination apparatus or microscopes especially built for this purpose. Like all so-called compound microscopes their optical system consists of an objective and an eyepiece, both representing a combination of several lenses in a mount. The objective is generally brought very close to the object. It receives the light-rays directly from the object and forms at the other side at a much greater distance an enlarged but inverted and reversed image. The eyepiece receives the rays which are diverging from this image, as if they proceeded from an object actually occupying its position, and brings them to the eye. Precisely like an ordinary pocket-lens brought close to the eye, it magnifies the image and makes it appear much closer to the eye than actually is the case.

Unilateral Illumination. The simplest way to illuminate an opaque object is to use a direct beam from an ordinary microscope lamp furnished with a movable condenser lens. The light is collected in a point at the spot where investigations are to be performed. High intensity light bulbs or arc-lamps serve best with this arrangement for the microphotography of soil spaces

where smaller magnifications are mostly required because of the necessity of obtaining a picture of the greater part of the interior of the spaces.

The so-called oblique illuminators are constructed on a similar principle. They consist generally of a low voltage bulb in a tubular mount which contains a condenser lens. An illuminator of this kind is used by the author for the field equipment of his soil microscope (fig. 18). An excellent oblique illuminator is manufactured in the Epi-lamp 8 by C. Zeiss, Jena (fig. 1). This illuminator is mounted on a revolving carrier which allows it to turn through an angle of some 220 or 300 degrees, limited only by the stand or milled focusing head. It is also possible to alter the angle of incidence of the light upon the object from about 22 to 45 degrees by displacing the illuminator along the arc of the curved carrier. The apparatus contains an 8 volt 0.6 amp. lamp which must be used with a resistance or with a transformer in the case of alternating current. The lamp is placed in a special centering holder which may be focused by altering its distance from the condenser. The latter is an aspherical lens of large aperture ratio. Between lamp holder and condenser filters heat absorbing glasses may be interposed. The Epi-lamp 8, being fixed to the microscope independently of the objectives, remains attached to the instrument while changing objectives.

An oblique illuminator which may be used in connection with high intensity microscope lamps and arc-lamps is built by C. Reichert, Vienna. It consists of a totally reflecting prism and a slightly concave hollow chromium mirror which may be fixed on the objective (fig. 2). The apparatus may be used with objectives of an initial magnification up to 34 times (Reichert objective No. 5).

The unilateral lighting of inclined illumination gives plastic images producing strong shadow effects. The latter are the reasons oblique illuminators make the relief of space walls or split planes of soil remind the observer of the light and dark contrast shown by the moon's surface. The inclined incidence of the light sometimes makes the satisfactory illumination of deeper soil spaces difficult. Since it is possible in the majority of cases, however, to vary the direction of the light both in azimuth and in altitude by displacing the illuminator or the object the difficulties may be mostly overcome. Inclined light may be applied only to microscopic investigations with lower magnifications. In some cases, however, satisfactory magnifications up to 400x

may be obtained. Direct unilateral lighting is of particular use in the performance of the common micromanipulations needed in micropedology, because the construction of the apparatus as well as the larger working distances of the objectives allow easy handling and easy introduction of the microtools into the soil spaces. This type of illumination allows the application of all objectives of standard type the working distance of which is not too narrow. C. Zeiss manufactures an achromat objective 20/0.40 especially designed for observations with Epi-lamps, and an achromat objective 40/0.65 for the use of the Epi-condenser D which is described later.

Bright-field and dark-field illumination. The illumination of an object with reflected light may be produced according to two principles. In the case of the so-called bright-field illumination the object is lighted in such a way that its reflecting planes, oriented vertically to the axis of the microscope, reflect the light rays into the objective. If vertically oriented planes are preponderant, the object will appear bright.

In the case of dark-field illumination in lighting the object, no light is thrown into the objective by the reflecting planes oriented vertically to the axis of the microscope but only by some of those which are inclined to it. Thus, in a large part, the object remains dark. If the horizontal planes are not smooth, but rough in their surface formation, they also will throw some diffuse light into the objective in spite of their orientation vertical to the microscope axis.

Apparatus for bright-field illumination. Bright-field illumination plays an important role in metallographic microscopy in which reflected light had been used long before its application in natural science. In all metallographic microscopes the light rays from an arc-lamp, a microscope lamp or a low voltage light bulb attached in a tubular mount laterally to the microscope enter a special housing above the objective. They are reflected by a prism, a plane glass plate, or in some cases by a small mirror in a more or less right angle. Traversing the objective they are concentrated and brought to the object by the objective lenses. In the case of a reflecting prism, which must be arranged in a lateral position leaving half of the microscopic picture uncovered, the light rays are reflected only through a half of the objective, lighting the object from only one side (fig. 3). In the case of a reflecting glass plate vertical light is produced (vertical illuminator). The intensity of light is considerably smaller but the microscopic field is entirely uncovered and the picture is

illuminated uniformly, not only unilaterally. Mirrors used instead of prisms or glass plates may be semicircular in shape or constructed as small strip mirrors. Semicircular mirrors work in a way similar to the reflecting prisms. Bright-field illuminators allow the application of both ordinary and polarized light (fig. 3). In spite of this they are of minor importance in microscopic soil investigations because they produce only pictures which show no shadows; thus the relief of torn soil surfaces appears like a level plane. They are more suitable for ore and metal investigations where pictures with thin and sharp contours are desired.

Apparatus for dark-field illumination. Dark-field illumination may be unilateral or circular. Unilateral illumination may be obtained by using direct light beams of high intensity microscope lamps or oblique illuminators as were described above.

By circular dark-field illumination the lighting of the object takes place in a radially symmetrical manner from all sides. The effect of the illumination is very similar to that of ordinary diffuse daylight. Strong unilateral shadow effects are eliminated. An object under dark-field illumination appears in its normal colors as it would by ordinary daylight reflection, whereas under bright-field illumination the colors are often changed by the various reflection conditions.

The oldest apparatus constructed for circular dark-field illumination is the Lieberkühn-mirror. Variations of it are still manufactured and used today. Figure 4 shows a ring mirror condenser of C. Reichert. The apparatus consists, in the main, of a more or less concave annular mirror. This mirror condenser is attached to the microscope substage in such a way that the objective is placed in the center of the mirror ring. The apparatus may be used with any microscope which has an aperture of sufficient width in the center of its stage. The object is placed on a special slide generally furnished with an opaque circular black area. The object should not be larger in diameter than the diameter of the opaque area which must be placed with its center coincident with the optical axis. The light rays from an ordinary microscope lamp are reflected by the normal mirror of the substage and pass the central aperture of the stage in the form of a ring, being screened in the center by the opaque area of the slide. The concave parts of the ring mirror then reflect the light rays in the form of a cone upon the object, concentrating them to a point or small circle (fig. 6). The mirrors may be easily interchanged with others of different concavity. Highly

concave mirrors allow reflection at a small angle which enables the application of objectives of comparatively low working distance. Thus, rather satisfactory magnifications of about 400x may be obtained. The apparatus, being fixed independently to the substage, allows an easy changing of the objectives (fig. 5).

A disadvantage of the round mirror condenser in its application to micropedological investigations is the restriction in the size of the object. Only soil fragments smaller than the opaque circular area of the microscopic slide can be used. The position of the condenser mount, covering practically all the space between the front lens of the objective and the surface of the object prevents, furthermore, a satisfactory introduction and handling of the microtools in the performance of micromanipulations.

Limitations of use for smaller objects is avoided by the illuminator manufactured by Bausch and Lomb (fig. 7), which apparatus, however, can be used only with lower magnifications. The main difference in construction consists in the fact that the light is produced from six minute light bulbs around the inside of the ring mirror. The illumination is thus independent of the lighting apparatus of the microscope substage which enables its application to larger bodies. The bulbs of 2.5 volt and 0.3 amperes have a diameter of about 3 mm. They may be secured in either clear or daylight glass. Each bulb is placed in an individual concave reflecting surface (fig. 8). The bulbs are supplied with a transformer with variable resistance and switch for 110-volt, 50- or 60-cycle A. C. or with a converter for use with D. C. Since the mirror ring cannot be interchanged with others of different concavities the application is limited to certain types of objectives down to a working distance of 16 mm.

Another construction of the ring mirror condenser type is represented by the Epi-mirror of C. Zeiss (fig. 9). The advantages of this apparatus are a wide range of utility, quick changing of objectives, and the possibility of introducing microtools. Although it can be applied only to objects of limited dimensions, their size can be comparatively large. When an adapting ring of 8-20 mm. height between the mirror and its support is used, the height of the object can extend up to 11 mm. with a diameter of 45 mm.

The annular mirror, which is much larger in size than those of any of the instruments described previously, rests on the stage of the microscope and is provided with a narrow flange which fits into the opening in the stage. For stages with small

apertures an adapter with a conical aperture is supplied. The condenser is used with a 6 volt lamp of 8 candle power (1.1 amp.) which is placed into the condenser sleeve of the substage of the microscope instead of its condenser. The object is placed on a Uro-glass resting on an annual support. It can be used as a mechanical stage by means of two adjusting screws and a spring pin. A rotating azimuth stop may be laid upon the Uro-glass plate which will permit a cone light of 80 degrees aperture to fall on the object.

The Epi-mirror is suitable with objectives from about 40 mm. focus up to and including oil immersions. High power objectives, however, are less satisfactory on account of their very small working distance. They are also liable to halation owing to their large aperture.

The annular mirror system of illumination reached its highest attainment in the construction of small mirror condensers largely of glass which are placed into a special mount around the objective and onto which the light is reflected from above by an annular plane mirror inclined at 45°. This arrangement is most suitable for soil investigations when the application of higher magnification is desired. Figure 10 shows a pattern of the Epilum apparatus of C. Reichert which is used also by the author in combination with his soil microscope described later. The light source in the form of a 10 volt, 0.6 ampere bulb is mounted with a condenser in a tube which is attached laterally to the apparatus (fig. 19). The center portions of the light are cut out by a central sector or diaphragm. The rays form a cylindrical mantle of light entering the apparatus from the side and fall upon the plane annular mirror (S). They are reflected by this mirror to the annular glass condenser (K) which is placed in a second mount encasing the mount of the objective (O). The glass condenser, according to the outlined path of the rays, concentrates the light into a bright spot on the object at a distance equivalent to the working distance of the objective used.

Instruments constructed upon this principle with certain changes are Epi-condenser D of Zeiss, the Ultropak of Leitz (fig. 11) and the Epilum of Reichert (fig. 19).

In the case of the Epi-condenser D (fig. 12) the use of standard objectives is made posible. The apparatus is fitted with two light bulbs (8 volt 0.6 amp.) opposite one another, each with an aspherical condenser. The plane annular mirror is separated

into two parts represented by the hypotenuse surfaces of two 45° prisms. The objective to be used is screwed into an adapter and dropped into the slide housing of the reflecting prisms, which are provided with a central aperture for this purpose. Beneath the mirror housing a paraboloid condenser surrounds the point of the objective.

Figure 13 shows an Ultropack with polarizing equipment. This device has not been designed primarily for the observation of polarizing phenomena but chiefly to eliminate glaring images that may be caused through ordinary reflection.

Epi-condensers, Ultropacks and Epilum-objectives, which rely on the basic principle first used by Chapman and Aldrige in England and later by Beck, impose limitations on neither the magnification of the objectives nor the size of the object. They can be applied, however, only to surfaces which are fairly even. Therefore, the application of high magnifications in the observation of undisturbed soils is limited more by the nature of the soil than by the capability of the apparatus. Nevertheless, very satisfactory pictures of magnifications up to about 900x may be obtained in many cases.

With some instruments it is possible to change over from dark-field to bright-field illumination, i.e., from the system of the concave annular mirror condenser to the vertical illuminator. Among apparatus of this kind are the Epi-condenser W of Zeiss (fig. 14) and the Universal opaque illuminator of Reichert. The latter is used by the author in combination with his soil microscope (see following paragraph).

An illuminator in which the light source is placed in the reflector itself rather than outside, was constructed by A. Silverman in the so-called Silverman illuminator manufactured by Spencer (fig. 15). The light is produced by a single filament tubular tungsten lamp in the form of a circle (fig. 16). It is attached to the objective by means of three, spring-controlled, iris-like fingers which may be opened by pressing together two handles on the outside of the mount. With the lamp, which is made either of colorless or blue daylight glass, a resistance is used. The inclination of the illumination may be varied by raising and lowering the apparatus. A shutter may cut off the illumination from one-half of the field thus producing unilateral illumination. Good results are obtained with objectives up to 4 mm. focus, in some cases much shorter. When used with high power objectives only highly oblique illumination can be ob-

tained. The Silverman illuminator imposes no limitations on the size of the object and also may be used satisfactorily for low magnifications. The method of attachment to the microscope is particularly convenient.

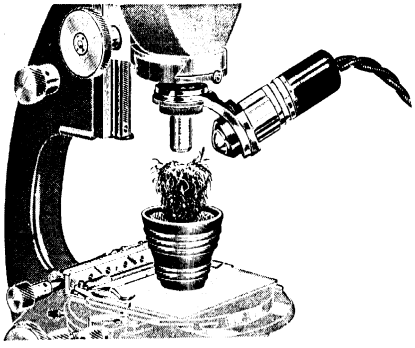


FIG. 1. Epi-lamp 8 (Zeiss).
About ⅓ actual size.

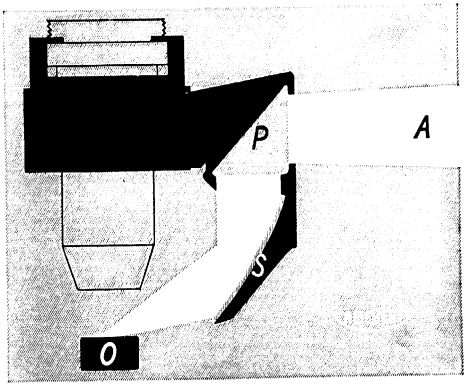


FIG. 2. Oblique illuminator of C. Reichert. (A) rays of the light source, (P) reflecting prism, (S) concave mirror, (O) soil culture dish.

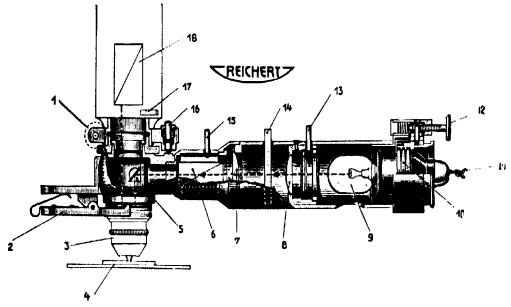


FIG. 3. Polarizing vertical illuminator (Reichert). (1 and 16) Centering screws, (2) objective clutch, (3) objective, (4) object, (5) reflecting prism, (6) polarizer, (7 and 8) condenser lenses, (9) light bulb, (10) bulb mount, (11) kabel, (12) centering screw of bulb, (13) lever for diaphragm, (14) light filter, (15) lever for polarizer, (17) gypsum plate, (18) analyzer.

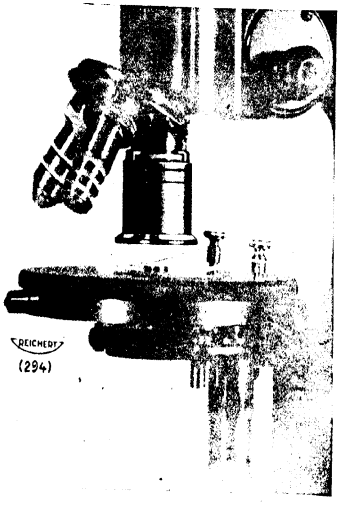


FIG. 4. Simple ring mirror illuminator (C. Reichert).

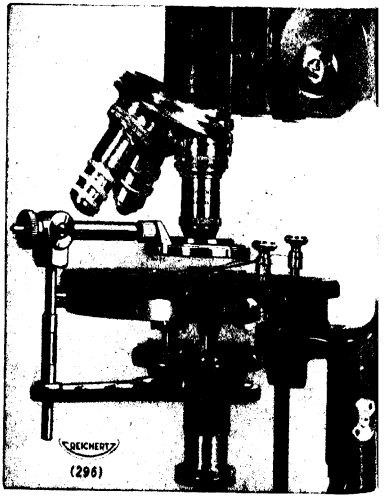


FIG. 5. Ring mirror illuminator attached to the substage (Reichert).

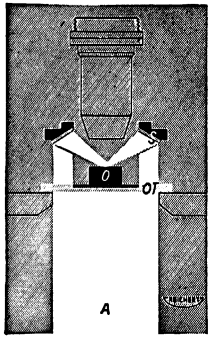


FIG. 6. Path of light rays in ring mirror illuminator. (A) rays from light source, (OT) slide, (S) mirror, (O) soil culture dish.

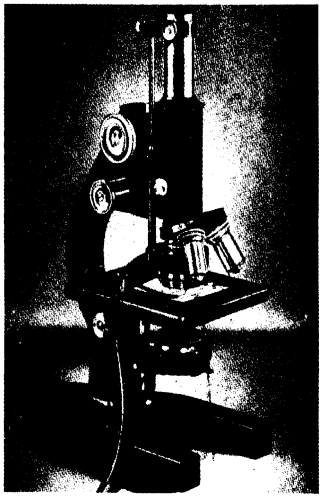


FIG. 7. Surface illuminator of Bausch & Lomb.

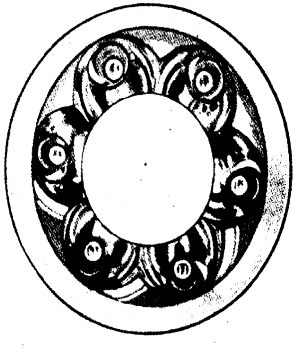


FIG. 8. Arrangement of the light bulbs in the surface illuminator of Bausch & Lomb.

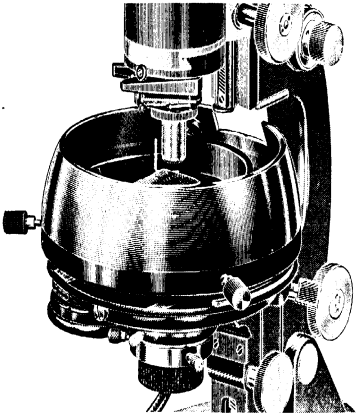


FIG. 9. Epi-mirror (Zeiss).

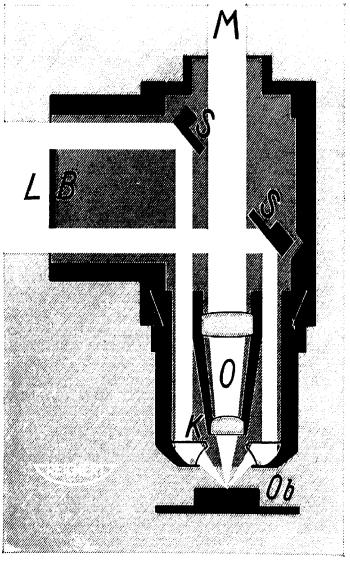


FIG. 10. Path of light rays in the "epilum" illuminator (Reichert). (L) light rays from light bulb, (B) central diaphragm, (S) annular mirror, (K) annular glass condenser, (Ob) object, (O) objective, (M) light rays reflected into the microscope.

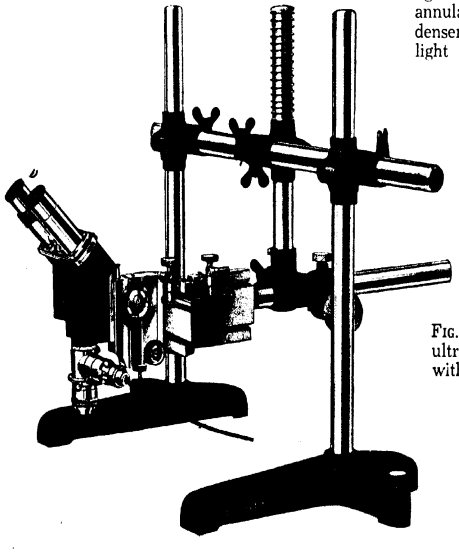


FIG. 11. Microscope with ultropack on pillar stand with cross motion slider (Leitz).

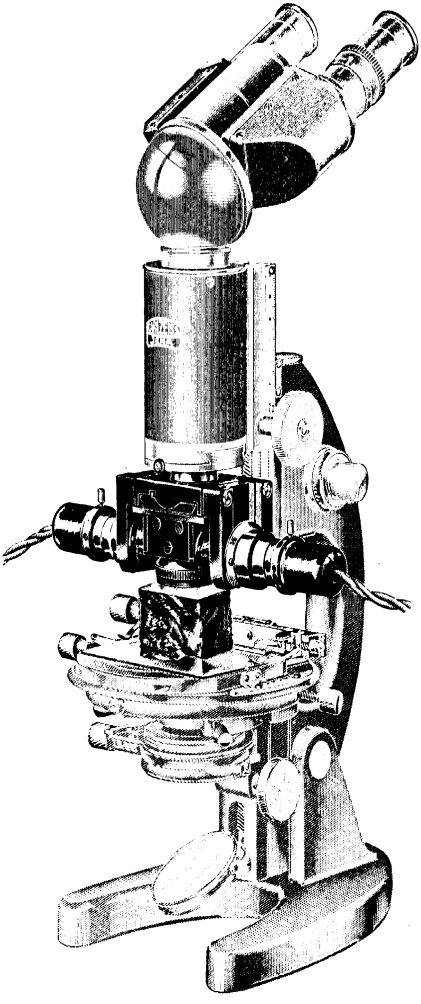


FIG. 12. Epi-condenser D (Zeiss).

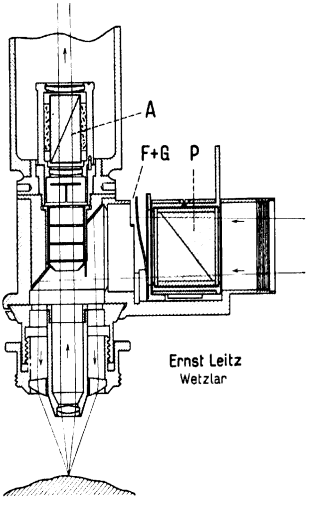


FIG. 13. Section through the ultropack with polarizing equipment (Leitz).

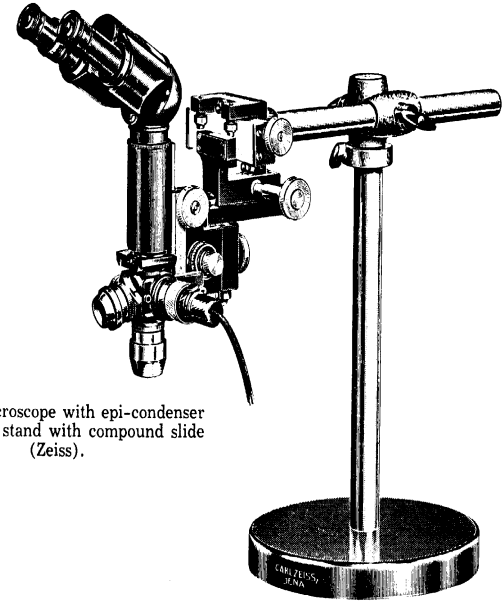


FIG. 14. Microscope with epi-condenser W on pillar stand with compound slide (Zeiss).

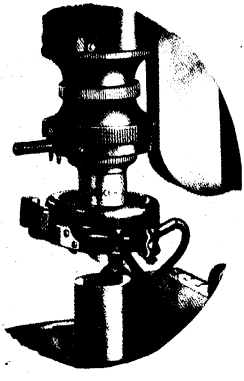


FIG. 15. Silverman illuminator (Spencer)

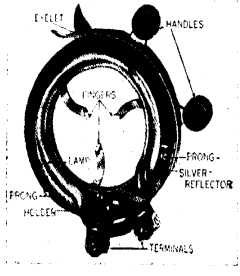


FIG. 16. Holder and lamp of the Silverman illuminator.

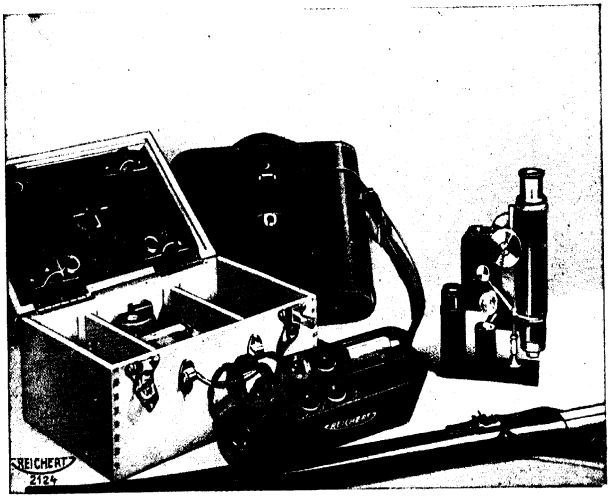


FIG. 17. Soil microscope folded together (Reichert) with leather box and case for cross-slide stand.

FIG. 18. Soil microscope (Reichert) with cross-slide stand attached to the wall of a brown earth profile. (In the leather box is a storage battery for the oblique illuminator.)

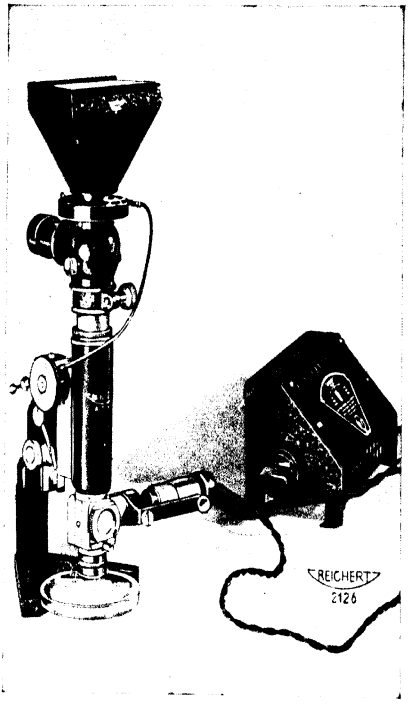
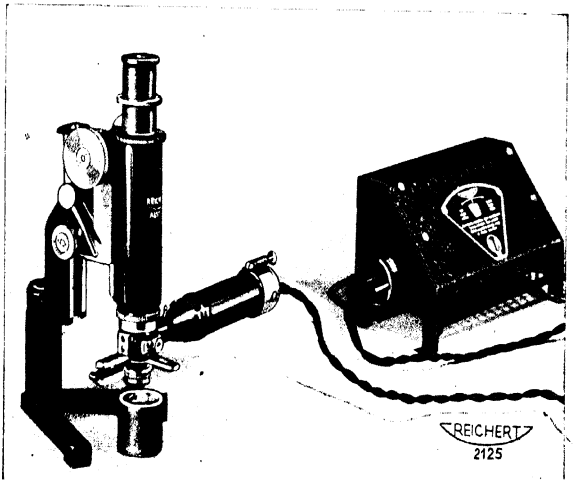


FIG. 19. Soil microscope combined with Epilum-Universal Illuminator and Czerny attachment camera.

FIG. 20. (below) Soil microscope with polarizing opaque illuminator (Reichert).



CHAPTER II

The Soil Microscope

All sciences related to soil science have specialized microscopes (petrography, microbiology, microchemistry). Most of these sciences developed highly specialized methods long ago. Pedology also needs a specially developed instrument. The essentials of a special soil microscope may be summarized as follows:

1. It requires, primarily, incident light equipment for moderate and higher magnifications. The necessity for investigating the interior of microscopic cavities demands specialization in incident light equipment.
2. For the investigation of bigger soil clods or fragments the tube of the microscope must be so constructed that it can be raised to a much greater height than usual.
3. The necessity of using the microscope in the field calls for a light and portable construction so it can be carried on excursions.
4. The instrument should be constructed so that it may be fixed on profile walls for prolonged observations.

The requirement for the application of higher magnifications is made because the smallest ingredients in soils are the most active and most important. This refers to inanimate formations as well as to microorganisms. Therefore, we must always attempt to develop methods in a direction such that an investigation of the smallest components and organisms in the undisturbed and living soil is made possible. Micropedology also differs considerably in this respect from microscopic petrography where high magnifications are generally not required.

The author has tried to consider all these requirements in constructing a soil microscope which is built and for sale by the optical works of C. Reichert in Vienna. It is a solid and normally constructed microscope for different types of incident illumination, which can be used with all normal objectives, eyepieces, and accessories, but it can still be folded together into a slender, easily portable form. With its field equipment, which

is primarily necessary for examination of soil profiles, it can be put into a small leather box in which it can be carried like a camera (fig. 17).

In order to make it ready for working, the feet of the stand are pulled apart; the support of the illuminator, after loosening its lateral screw, is turned out, and the tube is pulled out to the normal length, or 160 mm.

The field illuminator (oblique lamp) may be used with objectives down to a working distance of about 4 mm. which corresponds to an objective magnification of about 45x. In the field a small storage battery (10 volt, 0.7 amp.) or two or more dry batteries may be used. Sunlight may also be used, either directly or with a daylight mirror. An objective guard prevents the bottom lens of the objective from touching the soil.

In order to be able to fix the instrument on the profile wall so the investigator will have his hands free for manipulations, another kind of stand must be used which is designated as a "Cross-Slide Stand." The whole instrument, with the Cross-Slide Stand, is attached to a small working table, which is fixed on the profile wall by two pointed metal rods. The Cross-Slide Stand consists primarily of two crossed slides, which allow the microscope to be moved to every point within an area of about 3 inches in diameter. The arrangement allows prolonged work on a certain point or part of the profile wall (fig. 18).

Of particular necessity is the ability to change the stands in the easiest and most practical way. For this purpose a swallow-tail guide, a slide of trapezium-shaped cross section, is used. The center part of the swallow-tail is attached to the instrument, an outer part to each of the stands. The center part may be tightened to the instrument or loosened by means of a lever on the side (fig. 17). In order to change the stand the lever is placed in a position vertical to the slide. The instrument thus may be easily removed from its stand and placed into the slide frame of the other stand. It is fixed to the latter by putting the lever to a slant position either upwards or downwards which results in tightening the center part of the swallow-tail to the instrument and to the framing rims of the outer part.

In the laboratory the soil microscope is used with the vertical stand which we designate as a Hand Stand. This stand can be fixed to the working table with a special table clamp. For low magnification and for the performance of microtechnical work, the unilateral oblique illuminator used with the lighting current, and a universal resistance is most satisfactory. For obser-

vations under high magnifications the instrument is connected with an Epilum-Universal Illuminator (fig. 19) or an Opaque Illuminator (fig. 20). The latter allows the application of all types of incident illumination with higher magnification, as well as the application of polarized light in combination with a vertical illuminator. For the use of polarized light the ordinary tube of the microscope must be interchanged with another tube containing an analyser. In the majority of cases the equipment consisting of an unilateral oblique illuminator with objectives 4x, 10x and 16x, the eyepieces 7x and 16x (with removable micrometer), and an Epilum-Illuminator with the Epilum objectives 30x and water immersion 60x, will be sufficient for all types of micropedological investigations.

As to field equipment, the unilateral oblique illuminator with objectives 4x, 10x, 16x and the eyepiece 7x and 16x, will be suitable for all general work. This equipment may be placed easily into the leather box. The Cross-Slide Stand will be taken to the field only when prolonged investigations on profile walls are intended.

The Epilum water immersion objective 60x is of particular use for laboratory work with the highest magnifications, especially when performed on soils in a moist condition. Disturbances by condensed water are eliminated, the illumination and clarity of the picture is considerably intensified, and smaller soil organisms may be observed *in situ* and *in vivo*. The appearance of the soil with this magnification is very striking, resembling a formation composed entirely of glassy and transparent constituents comprising elements of both animate and inanimate nature. In using the water immersion only fairly plane surfaces of soil fragments may be investigated. A drop of water is added to the spot to be examined and the surface then covered with a cover slip. Finally another drop of water is placed on the cover slip and the bottom lens of the objective cautiously dipped into it and lowered until the picture appears in focus.

CHAPTER III

Performance of Micromanipulations

By microscopic investigations of undisturbed soil we observe a great number of individual formations of both animate and inanimate nature in the soil spaces. The desire to investigate them individually requires the ability to handle them individually, in other words, the necessity of manipulations which have to be performed in the microscopic environs of the organisms or inanimate formations. Manipulations in this respect which are used largely in micropedological investigations are:

1. Isolations and tranfers of microscopic objects, organisms or solutions from a soil space to a glass slide for the purpose of detailed morphological investigations with transmitted light (in some cases by use of high magnifications) or for individual microchemical or microphysical analyses;

2. Isolations and tranfers of organisms to artificial media suitable for their propagation in the form of cultures;

3. Introduction of objects, organisms or solutions into soil spaces for the purpose of experiments or chemical reactions;

4. Displacement or removal of objects, organisms or parts of space walls in order to render free other formations or space parts which were covered or screened by them;

5. Destruction of parts of objects or dissection of organisms for a similar purpose or for the performance of experiments, etc.

The means of carrying out these manipulations are provided by special working tools, the effective ends of which are small enough to be used in microscopic dimensions. They may be used either free hand or by means of micromanipulators.

1. MICRO-TOOLS

Since most of the manipulations necessary for micropedological investigations may be performed under low magnifications (50-200x), the refinement of tools indispensable in biological micrurgy is necessary in only very rare cases. The author prefers metal tools which are more durable and may be resterilized easily by flaming. They should be made of metals which do not form scoria on heating. These tools are made by the

worker himself by careful grinding on finest emery paper and oiled wet-hones and checking the progress continuously under the microscope. The prepared tools ready for use are kept in micro-test tubes or little vials in which they are prevented from touching the glass walls by pulling the handles through a hole of the cork stopper in the case of vials or through pieces of rubber tubing in the case of micro-test tubes (fig. 21).

Micro-needles. Two types of needles, coarse and fine, are used. The tips of coarse needles have a diameter of about 100μ and those of fine needles 40 to 20μ or less. Coarse needles are especially suitable for isolation of granular objects. They are dipped into glycerol or water, and granular objects touched by their points will then adhere to them and may be easily taken out of their environs. The top of the needle should be not much smaller than the object, otherwise the latter may not adhere enough to it. Objects larger than the point of the needle may adhere in some cases if the side of the tip is used.

Fine needles are used primarily for moving or displacing objects, dissecting or destroying parts of organisms or inanimate formations, and for isolating the smallest ingredients.

Micro-lancets. Tools with spear-shaped ends, the upper edges of which have been sharpened on the wet-hone, serve for cutting and dissecting, especially of objects isolated on microscopic slides. The wide surface of the spear blade is suitable for the isolation of larger objects.

Micro-spatulas. Micro-lancets, the points of which have been ground off and sharpened to an edge vertical to the tool-shaft serve as micro-spatulas. They are used like a microscopic spade or shovel. Such spatulas, the blades of which have been bent to a slant position (fig. 21), serve in combination with a fine pointed dry needle for the isolation of powdery material. Micro-spatulas are very useful in microchemical work for handling small quantities of substances.

Micro-forceps. The best type of micro-forceps for free hand manipulation is pictured in fig. 22. The points must be prepared on fine emery paper. The grinding is then finished on a fine razor wet-hone which has been oiled. The grinding must be done only on the outside of the points, otherwise the ends of the forceps would not touch each other sufficiently for the performance of isolations (fig. 23). The result of the grinding must be checked repeatedly by observing the changes of shape under a low power objective or most advantageously under a Greenough binocular. Micro-forceps are indispensable for isolating

all material which is not granular in shape, as for plucking single conidiophores of fungi or for picking up pellets of mycelium, single fungus hyphae, plant roots, humus fragments, etc. They serve also for isolating or displacing larger units such as wall bodies or aggregates. Microscopic animals of the type of soil mites are best isolated without destruction by seizing them with micro-forceps by one of their legs.

Automatic micro-forceps. The automatic micro-forceps in fig. 22, designed by the author and manufactured by C. Reichert, must be used in conjunction with a micromanipulator. Some formations in the soil (especially conidiophores of some fungi as Hyalopus) are so fragile that they are easily destroyed by free hand manipulation. Their individual isolation therefore is greatly faciliated by the more easily controllable movements of the manipulator. The tool consists of a metal tube 3.5 mm. in diameter which carries a pair of forceps at one end. The points of the forceps, which are bent somewhat downward, are held apart by spring tension. By the special shape of the forceps the points may be brought together by a rectangular metal collar (c,cs) when it is moved towards the tip. The movement of this collar is produced by means of a knurled threaded washer held so that it is free to rotate in the handle of the tool. The washer turns on a threaded metal rod running through the shaft of the forceps to connect with the actuating collar. By turning the washer the metal rod is driven forward or backward, resulting in very regular opening or closing of the forcep tips.

The forceps must be fixed into the tool-holder of the manipulator and the open points then moved toward the object until the latter is directly between them. The points are then closed and the tool removed from the soil space by the manipulator.

Micropipettes. Pipettes for microscopic manipulations are manufactured by pulling out glass tubes after heating them in a flame. The points of very fine pipettes are made after heating in a micro-burner. Mouth pipettes are connected by a rubber tube with a glass mouth piece at its other end. While performing the manipulation under the microscope the worker keeps the mouth piece in his mouth ready to draw in or expell drops of liquid at the desired moment. Pump-pipettes may also be used. These are connected by means of rubber tubing to a small glass or metal syringe. Pump-pipettes are especially suitable where more delicate work is required.

Micropipettes are needed for the isolation of objects from spaces filled with soil solution or present in coatings of capillary water on the space walls. They are used, furthermore, for removing or adding drops of liquids (reagents) and finally for the isolation of the smallest soil organisms generally not observable in the soil with unilateral oblique illumination, in order to prepare them on slides or to propagate them on artificial media.

For the isolation of small objects submerged in capillary water the point of the pipette is approached close to the desired particle or organism (protozoon). By removal of a drop of the liquid the object will be sucked into the opening of the pipette and may easily be taken out of the soil space (fig. 24).

Microplatinum wires (fig. 21). The finest platinum wire mounted in glass or metal handles serves mainly for the isolation of microorganisms. Pointed wires serve for the finest isolation work as, for example, the making of monocultures, i. e., cultures from a single spore of fungus. Hook-shaped wires are very suitable for the isolation of fungus mycelium. Wires with a flattened end (prepared by hammering) serve for opening sporangiophores and allow the removal of a larger amount of spores than does a pointed wire. Much larger amounts of spores may be isolated by platinum loops which also may be used for the isolation of small drops of liquid. In the matter of resterilization, tools of platinum wire are superior to all tools made of other material.

Orientation needles. It is usually a matter of great difficulty again to find microscopic locations which are required for repeated investigations, and this may sometimes be accomplished only with great loss of time and effort. The multiplicity of spaces of similar appearance and the possibility of seeing only a small part of the whole causes the observer to become entirely lost in this little world of microscopic formations. It may take hours to find again the original position, especially if the formations for which one is looking can be seen only with higher magnifications. The return to a definite position is much facilitated by the application of orientation needles, small pieces of glass thread of about 0.3 mm. in diameter and 2-4 mm. in length. The needles can be seen with the naked eye, especially by turning the soil sample until the light is reflected by their convex surfaces.

The needles are manufactured by using metal tongs to pull out threads from fragments of glass which have been melted

over a burner. For this purpose glass fragments of different colors may be used from which needles in red, brown, blue, green, etc. may be obtained. Colored needles allow a more specified orientation when more than one needle is used in one soil sample. The glass threads are cut with a scalpel to the desired length. Since the thread pieces have a tendency to jump away on being cut it is advisable to cover the part of the thread to be cut off with an overturned glass dish, under which the needles are accumulated (fig. 25). The needles may be collected and transferred with a soft brush to a little glass dish where they are kept ready for use. Needles for microbiological purposes must be sterilized.

The orientation needles are introduced microtechnically into the soil by means of micro-forceps or wetted microneedles. They are placed in the close vicinity of those formations whose re-discovery is desired (fig. 26). The worker makes a design of the outlines of the soil sample in his record book (a circle in the case of a culture dish oriented by a sign on the outside of the dish wall) in which the position of the orientation needle is marked by a dash. Close to the dash a point indicates the position and distance of the object from the needle. If more than one needle is introduced the dashes are provided with numbers to which a description is given in a legend.

2. ISOLATION OF MICROSCOPIC OBJECTS AND ORGANISMS

Isolation with two microscopes. A common method of isolation is performed with two microscopes, one of which is an incident light microscope, the other generally a microscope for transmitted illumination (fig. 27). On the stage of the latter a slide bearing a drop of water is placed. The manipulating hand is not kept free but rests on a supporting body of a suitable height. The height of the support is of special significance for the steadiness and sureness of the movements of the hand and should be about 1.3 inches lower than the position of the object to be isolated. For the support it is advisable to provide a number of wooden blocks of 4 inches in length, 2½ inches in width, and of varying thicknesses. The blocks are piled up to the desired height (fig. 27).

For the isolation, the object must first be brought into focus. After this, the working tool is introduced into the space between objective and soil surface. It is moved within this space until its image, which at first is indistinct, or the image of

its shadow appears in the microscopic field. The tool is then lowered until it yields a clear image, moved until its point is visible and the latter brought to the object. In the case where the images both of the tool and of its shadow are visible the tool is moved towards the shadow and in the direction where both images are diverging (fig. 28). After the object has been taken up, the tool with the object is brought to the other microscope where the water drop has previously been focused and the supporting blocks brought into the correct position before the isolation was started. The tool is immersed in the water drop and the object thus released. It sometimes happens that organic formations adhere to the tool with such tenacity that they are not liberated by immersion in the liquid. In this case the object can be removed from the tool by means of a fine needle brought to the water drop by the other hand.

Isolation with two microscopes has the advantage that both the soil space and the water drop are kept in focus and need not be moved. The worker may concentrate entirely on the manipulations to be performed. A disadvantage is the necessity of transporting the isolated object a considerable distance to the slide which means loss in time and the greater possibility of losing the object on the way to the other microscope. Therefore, isolation is more sure with a single microscope.

Isolation with a single microscope. In this case both the soil sample and the slide with the water drop are placed on a glass plate which must be moved after every phase of the isolation work so that alternately the soil space and the water drop are brought into focus. The work is much facilitated if both the object and the water drop are exactly at the same height so that both are in focus when placed under the objective. A small support which can be easily adjusted to the height of the soil space by a screw movement (fig. 29) is very practical for this purpose.

During the isolation with a single microscope the working hand is always resting in the same position on its supporting blocks which yields surer manipulations. The method, however, is less suitable if the relocation of the soil space is difficult. Furthermore, the necessity of placing the soil sample and slide on one glass plate allows only the examination of small soil bodies. In cases where relocation of definite spaces and the performance of isolations from the surface of large soil fragments are not required, the method is superior to all other procedures.

Isolation with a double microscope. In most scientific institutions some disused old-fashioned microscopes, now replaced by modern instruments, can be found. These old microscopes can be changed easily into instruments suitable for incident light and for microscopic observation of large bodies by removing them with their gear housings from their stands (especially where they are fixed to them with screws) and by attaching them with ordinary laboratory clamps to short but heavy tripod base supports ordinarily used in chemical work for mounting apparatus. They may be furnished with high intensity flash lights as unilateral oblique illuminators attached to similar supports of smaller size and lighter construction. Several flash lights may be connected in series with the lighting current in combination with a rheostat. Two of these microscopes attached to a single stand represent a double microscope (figs. 30 and 31). If their eyepieces are kept apart at a distance corresponding to the distance between the eyes of the worker they may be used as a comparison microscope. Two different objects, each placed under one of the instruments, may thus easily be compared with each other. The worker may either close alternately one eye or keep both eyes open; in the latter case a half-part of each of the two images will be clearly visible. If the soil sample is placed under one microscope and the slide (raised to about the same height by a support) under the other, isolations may be performed then in a manner very similar to that when two microscopes are mounted on different stands. The advantage of this arrangement is that soil sample and slide are close to one another, thereby greatly facilitating the work. Furthermore, both are constantly kept in focus. If both the microscopes are drawn closer together (fig. 31) the distance between object and slide is still further diminished. The working hand may rest then on the same support; the microscopes must, of course, be used alternately since the eyepieces cannot be kept to both eyes at the same time. If the distance between the focal points of the two microscopes is too great to allow the hand to rest in one position during the whole procedure the supporting block of the working hand is moved with the other (left) hand every time the working tool is moved. In the case of the movement from the slide back to the soil space the supporting block is pulled into a position somewhat in front of the two microscopes.

Revolving hemi-sphere stage. In order to place the soil space in which isolations are to be performed into correct position, a revolving hemi-sphere stage as pictured in fig. 27 may be used.

It serves for microscopic investigations in general and is indispensable for micropedological work since it allows the performance of observations on almost every point of a soil fragment. The revolving hemi-sphere stage consists of an upper half-sphere which fits into a corresponding concavity in which it may be rotated not only horizontally, but also turned vertically in all directions to angles up to 90°. On the flat plane of the half-sphere a cork disc is fixed. The soil fragment is held to it by a number of pins stuck into the cork and tightly encircling the fragment. Since this stage is not yet produced commerically, the worker is forced either to make it himself or to have it manufactured by an instrument maker. For this purpose metals with a low melting point, wood (prepared on a lathe) or plaster of Paris are suitable materials.

3. MICROMECHANICAL ANALYSIS

The term mechanical analysis, as applied in general soil science, means the mechanical grouping of the soil particles according to their sizes. It was first employed in this sense in the earliest stages of soil science when there were only two kinds of analyses, the "chemical" and the "mechanical." In view of the fact that other mechanical methods have been originated in the meantime the term is replaced today by many investigators by particle size determination (Korngrössenbestimmung, Körnungsanalyse). The term micromechanical analysis has a wider sense and means not only mechanical grouping of soil units according to their sizes but also according to other properties such as chemical composition, specific construction (intergranular braces, space deposits, aggregates, cleavage blocks, etc., explained in Part III), specific function (remnants of organisms belonging to the same group), etc. The term, micromechanical analysis, in the wider sense was originated and is in general use in microchemistry.

Micromechanical analyses are best performed with a single microscope, particularly in those cases in which the separation of components is made from soil debris on a slide, and these are then collected on another slide or on another section of the same slide. When the isolation of a large number of components is made from spaces, which are difficult to find again, the use of a double microscope is more suitable.

Micromechanical analyses are made in order to obtain a large amount of certain components for the performance of special chemical, optical, or morphological investigations.

4. CONSTRUCTION OF A SIMPLE MICROMANIPULATOR

As mentioned in a previous paragraph, certain isolations are difficult to perform free hand and need the application of a manipulator. Micromanipulators are especially necessary when very fragile or very small objects are to be isolated, or when particularly delicate manipulations are to be performed. Manipulators are expensive instruments and range in price as high as microscopes. However, a micromanipulator designed by the author for micropedological work may be built at very little cost by the worker himself. Since, in the equipping of new soil microscopy laboratories, most attention must be given to the purchase of optical apparatus, detailed instructions for the construction of a micromanipulator for micropedological purposes will be of particular help in lowering the costs of the necessary equipment.

The apparatus can be used only if a microscope with a circular revolving stage with lateral centering screws (most common with biological microscopes) is available. The construction of the manipulator is based upon the principle of using the centering screws for the movement of the microtools. The tool holder is therefore fixed on the stage, the object is placed on a special stage which is attached to the condenser mount of the substage and which may be raised or lowered with the substage focusing screw.

A circular revolving microscope stage generally consists of two principal parts, an upper part with a projecting ring which fits into an open space in the lower part (fig. 32). The lower part is furnished with a spring loaded pin with an adjusting screw on either side at an angle of 130° to it. If both screws are driven into the open space inside the stage, i. e., if both screw heads are turned left, the projecting ring and the upper stage fixed to it will be moved in the northern direction (the different directions of the microscopic field are named after the directions of the compass, north meaning the direction opposite to the microscope pillar) thus compressing the spring behind the pin. If the tips of both screws are withdrawn from the space (both screws turned right) the upper stage part will be pushed in the southern direction by the pressure of the spring on the pin. If only one or the other of the screws is turned separately inward or outward, the movement will be NW, NE, SW, or SE. If the screw heads are turned in opposite direction to one another the movement of the stage will be either west or east.

Under the microscope the latter movements are produced in practically a straight line since they take place only within microscopic distances.

The same movements will be produced by a microtool, the tip of which is in the focus of the microscope if the tool is fixed to the revolving stage. Since the microscopic picture appears reversed and inverted, the movements of the tools will also be reversed under the microscope. Figure 33 gives the principal movements of the tool tip under the microscope resulting from the different ways of turning the screw heads. In order to simplify the drawing the screw heads are pictured side by side rather than at an angle to each other.

For the construction of the tool holder (fig. 34), first a square shaft of about 6 mm. diameter and 4.5 mm. long is made (s). The tool clamp (tc), a metal piece with a u-shaped groove in which the tool (t) is fixed in the simplest way by means of short sections of rubber tubing (b), is soldered to a rest (r) showing rectangular cross section. The latter is recessed in such a manner as to allow it to slide in the shaft without appreciable sideplay. The rest is held firmly to the shaft by another section of rubber tubing. The shaft is soldered to a stage clip by which the toolholder may be easily attached to one of the clip-holes of the microscope stage and easily removed from it.

The tool connected with the stage by means of the toolholder will thus respond to every movement of the centering screws, but the object if on the stage would move as well. The object, therefore, must be placed on a special stage independent of the microscope stage (fig. 35). This manipulator stage consists of a circular metal plate of a diameter of about 65 mm., attached to a column of cork which fits into the condenser mount of the substage. The condenser must be moved before placing the manipulator stage into the condenser mount. The manipulator stage can be moved upwards and downwards by means of the substage focusing adjustment. These movements are sufficient if manipulations are performed under low magnifications. They are much too coarse, however, if high magnifications are used. In this case the focusing screw must be furnished with a long lever, which is done in the simplest way by attaching a very light laboratory clamp to it (fig. 35). This simple type of adjustment yields surprisingly good results. A lever of a length of 23 cm. allows the performance of movements of a single μ.

The above description represents the simplest type of construction. Slight amendments, such as replacing of the rubber tubings by screw attachments, etc., will be of advantage for handling the apparatus. The manipulator may be constructed also for use with transmitted light. The manipulator table must be furnished then with a central aperture and must be fixed on a cylindrical support which is attached to the outer wall surface of the condenser mount.

The apparatus has the advantage that all the horizontal movements can be performed with the two centering screws so that the working hands are always kept in the same position. In spite of the simple construction the movements are perfectly satisfactory even with high magnifications.

The main disadvantage is that only one tool can be moved, so that a combined manipulation with two tools cannot be performed. Furthermore, a fine horizontal movement of the object can be produced only by free hand. The latter makes the isolation of single bacteria in moist chambers complicated though not impossible.

Performance of manipulations. Before the manipulation is started the working tool is fixed in the toolholder and its tip focused under the microscope with low magnification. The tip is moved then west and east. If the tip cannot be moved in either of these directions entirely to the margin of the microscopic field, its position must be rectified by cautious moving of the toolhandle in the tool clamp of the holder until the tip of the tool touches the margin of the field. The same is repeated to the north and south after revolving the stage through 90 degrees. The tool may be moved then to every visible part of the microscopic field.

After the rectification of the tool position the tool tip is brought close to the surface of the soil sample. This movement is performed with the naked eye by raising the substage. The soil space and the object in it is then brought into focus. The next movement consists in approaching object and tool tip so that the latter yields an indistinct but visible picture when the first is in focus. The tool tip is then placed directly above the object when an approach from above is intended. Raising the manipulator stage in this case will result in a touching of the object by the tool tip. Alternated focusing of object and tool tip may assure the worker of the position of the latter and of its distance from the object. If an approach from the side of the object is intended, the tool tip is placed at some distance from it

before the manipulator stage is raised. If both the tool tip and the object in focus indicate that they are at the same height, the tool will touch the object from the side when it is moved towards it. Every movement with the manipulator can be carried out with great steadiness and exactness. Likewise, manipulations which need prolonged and complicated action may be performed with perfection.

CHAPTER IV

Microscopic Field Investigation

Soil as a living formation in nature can be found only in the field where its appearance, its processes and its original life undergo remarkable changes throughout the year. As well as the different phases of the soil dynamics caused by the climatic changes of the seasons, differences may be observed also from one year to another. Finally, every soil tends to develop in some certain direction and may after a long period arrive at its predestined condition if the factors influencing the development are not changed in the meantime. Every soil represents a certain stage in this development.

All these characteristics which make the soil resemble a living body and which make us understand that authentic pictures of the soil and the processes in its interior can be obtained only in its natural habitat, indicate the great importance of field investigations.

Suppose a subsoil sample is taken in the early spring in the form of a block of 1 cdm. and the sample brought to the laboratory. All precautions against changing its natural fabric are observed. The soil block is now a new formation with a new surface which is only 5 cm. from the center. If the laboratory has a higher temperature, rapid evaporation will begin on all surface planes except the bottom. The soil solution will be drawn continuously to the surface where the substances, dissolved or dispersed in it, will effloresce. If the soil solution contains large quantities of salts then this process can be observed with the naked eye. The surface of the block gradually will become covered with a white crust. Furthermore, we can observe that the deposits of salts reach the highest density on the corners and edges of the soil block because of the higher evaporation at these parts and the strong capillary draught in their direction provided the soil has a uniform capillary system. In a further stage some of the salts cannot reach the surface and will be deposited in the soil parts below the surface. Then deposits may form different layers according to different recession stages of the soil solution.

We see that the soil sample has developed on its outer parts illuvial layers which never existed in the natural soil. They correspond to an eluvial zone in the center of the soil block. We cannot see these differences with the naked eye if the soil solution does not contain large amounts of salts or colloids. We are able, however, in most cases to determine the changes with the microscope. The soil block may differ considerably in its construction from a corresponding soil part in nature.

Suppose the soil block were not rich in soluble salts or dispersable colloids, though rich in nutrients and decomposable organic substances. After a short time we would see with the microscope fungi developing on the surface. The development might attain such a degree that the fungi would be seen with the naked eye. Where is the highest density of growth? Again it is on the corners and on the edges of the soil block, i. e., on the surface parts with the highest evaporation and the strongest capillary draught. We see almost the same picture as resulted from the salt efflorescences. Is the growth of fungi somewhat similar to the development of the salt efflorescences? There is some similarity between them. The fungi in this case take the water, the mineral nutrients and the organic substances they need from the soil solution. There is furthermore a potential difference in regard to water between the saturated soil and the unsaturated air. The fungi merely benefit by this and develop their body substance in the air space in a way quite similar to that in which the efflorescences develop their body substances in the air space. We see that the figurative term "efflorescence" is in its meaning surprisingly close to the derivation (see K. Schultze, p. 17). What we desired to show with our example is that the soil block taken from the subsoil developed a flora on its new surfaces which would never have been there in the natural environs. Even the species of fungi found on the sample surface probably could not be found at all in the natural subsoil except in the form of undeveloped spores. They could develop as the conditions became favorable for them.

The soil in the laboratory is so easily changed in its microdynamics and microscopic life that we may say that the real dynamics and the real life of the soil in nature are but little known. They can be as little observed in the laboratory as can meteorological observations be made on air samples brought to a weather station. The very nature of the soil in its natural habitat would demand a similar system of perma-

nent records as used in meteorology. It may be quite possible that field investigations will become so important that future soil investigators who are studying special problems will prefer to have a field laboratory in a trailer or tent which would permit them to work in close proximity to a particular soil. These field laboratories would be particularly useful in the performance of direct microbiological investigations and for making cultures of certain microorganisms by direct transference to different artificial media.

It is true that one can take undisturbed soil samples in small glass dishes and preserve the life in them by providing moisture, air and temperature conditions optimal for the soil organisms present in them. Life can be observed in the spaces of these soil samples for a long period of time. This life, however, relates only in a certain degree to the life in the interior of the natural soil. It resembles that type of life which is to be seen in cultures of animal tissues. We find similarities between the life of the tissue cultures of animal kidney, liver or lung in incubators and the life of the respective organ tissues in the body of the living animal. Still the cultures of the tissue parts taken out of the animal body are following different courses of life. In observing the life in the spaces of undisturbed soil samples one may approach closer to an understanding of the real soil life than by any other method. However, it is not the life of the natural soil. It must be borne in mind that the method represents only a substitute.

Laboratory investigations are and will always be needed, but we shall never know the real microscopic life of the soil by studying it in the laboratory only.

To what degree the changed dynamics of the soil caused by human interference may influence the whole appearance of the soil is shown by the appearance of old profiles. The pedologist working in the field knows that the investigation of old, dried-out soil profiles may lead to false statements. He knows that he must make new profiles or at least slice off the old to a great extent. How are the differences in appearance produced? When a profile is made the soil is given a new side surface. If the soil is wet, the flow of the capillary water will not take place upwards but in the direction of the new surface. Due to the shorter distance to the new surface the capillary flow in the lower soil parts will be much stronger than under normal conditions. After some time the profile wall will be covered with different efflorescences which may

change entirely the original color and appearance of the various layers.

Shall we therefore avoid entirely the investigation of old profile walls? Though the use of old profile walls is in general repugnant to the pedologist, old profile surfaces allow the observation of something otherwise difficult to see, i. e., the salts and colloid substances dissolved in the soil solution of the different horizons or horizon parts. The dissolved substances are almost horizontally drawn out of the different layers when the soil dries out and are accumulated on the surface of the wall. Sometimes their nature may even be identified by their appearance, in other cases they may be identified by microchemical or staining reactions. In other words we may also investigate successfully soil profiles or soil pieces in a quite unusual state as soil clods exposed to a rain shower, or soil pieces dried out in the sun, and make observations which may be of particular value for the understanding of the dynamics of given soil. We have only to be conscious of the type of material we have and under what conditions the changes in the natural fabric took place.

The technique of field investigations. The simplest way to use an incident light microscope (soil microscope) for the investigation of the soil surface and the humus layer is to assume a lying or half kneeling position on the ground. There is a way of observing the soil in a sitting or standing position by using types of microscopes which can be fixed on specially built stands at a considerable distance from the object (Fernlupen, Zeiss; Heimstädt's Stereoaufsatz, Reichert). These instruments, however, do not allow a high magnification; the long distance between them and the object in view, furthermore, do not permit of micromanipulations which are very essential, for instance, in the isolation of organisms. If it is not necessary to investigate large areas and the microscopic work is limited to one place then we may form a kind of working table of the natural soil surface by digging out a pit close to it which allows the investigator to stand or sit on a camp stool. The different soil layers may be laid wide open with a little trowel; the spaces, however, must be opened by breaking the soil with the hands or by splitting with an awl-shaped needle.

For the propagation of certain microorganisms found by direct microscopy (mainly fungi and actinomyces) it is advisable to bring different artificial media in tubes to the field, and in addition a set of microplatinum wires and an alcohol burner.

Before the isolation is made the appearance of the organism and the habitat must be described and noted. With this method we are able to obtain cultures of a number of characteristic organisms of a given soil without taking any soil sample to the laboratory.

In order to obtain true life pictures of different phases in the activity of bacteria and small protozoa the method may be supplemented by the Rossi-Cholodny technique (18, 19).

The microscopic investigation of the profile wall is carried out by holding the microscope to it with the free hand, or, for prolonged work and the performance of manipulations, by attaching specially built microscopes (soil microscope, see page 34) to the profile wall. In cases where a soil microscope is not available, an investigation of soil fragments broken out from the profile wall may be performed with an ordinary incident light microscope. The investigation may be made directly on the border of the profile pit.

As to the light source for outdoor microscopic investigations the direct sunlight, in some cases collected and directed by a concave mirror, will meet all requirements. In the forest and on cloudy days the low volt lamps of the illuminators may be supplied with current from dry cells or storage batteries.

CHAPTER V

Soil Sampling

In spite of the fact that soil as a natural formation, especially with regard to its real processes and its real life, may be found only in the field, microscopic research in the field, for various reasons, will be carried on only to a limited extent. Sudden changes of weather which may interrupt any prolonged study are not the only difficulties. Every outdoor worker knows that wind and dust may be very troublesome in the performance of delicate investigations. Therefore, the desire of the worker will be to perform the finer and the more delicate work in the laboratory, especially when a greater variety of instruments and tools and more specialized working equipment are needed.

However, the soil samples may be taken only as a proof of the experience gathered in the field. They are taken to the laboratory because they can be investigated there in greater detail. Soil samples without exact description in regard to their origin, location and position in the profile have little value for scientific investigations.

As in petrography and paleontology the goal of our research is not knowledge of the properties of the dead and unchanging samples but an insight into former physical, chemical, and biological events in the soil which can be reconstructed by careful investigation of their present component arrangement. The dried samples have a similar relation to the living soil as the dead plants in a herbarium or the dead preparations of animals in a museum to the living organisms in nature. Continued observations of the phenomena have ceased to be possible and reconstruction from static detail must take their place as research methods.

The laboratory work will depend much on the kind of sampling adopted. The method of sampling and the state of the soil from which the samples are best taken depend on the type of investigation to be performed. Samples for microbiological purposes are taken best of soils in moist conditions;

samples for studying the soil fabrics are better taken from naturally dried soils.

1. ORIENTED SAMPLING FOR THE STUDY OF SOIL FABRICS

In dried out soil, the arrangement of the constituents will not undergo further change, and the moving components are fixed in final stage. The study of the arrangement of this final stage allows a reconstruction of the former movements.

In the case of dry and coherent soils a profile is opened and after general study of its different parts, a number of carefully chosen handpieces of soil have to be broken out of it. On every soil piece the orientation in the profile must be marked, especially the top side and the bottom side of every sample, in some cases the sides which are bound to another sample piece. With sufficiently coherent soils this can be done by sticking a piece of surgical tape on the sample piece on which the orientation is marked "J_1, J_2" (joint 1, joint 2), etc. Pieces broken out from the soil surface or from the surface of an old profile wall in order to study its surface efflorescences may be marked with "SS" (soil surface) or "PS" (profile surface). The orientation labels may be fastened with rubber bands on soil samples too soft to hold ahesive tape. A square piece of tape on which the orientation is marked is stuck to a rubber band. Its glued reverse side is covered then by another piece of tape of equal size so that the rubber band is enclosed between the two (fig. 36). It is advisable to prepare a set of marked rubber bands in the laboratory in order that they can be used without much delay during the field excursion. The original position of the soil piece in the profile may be marked also in the following way. The sample piece is laid in its right position on a sheet of paper on which the top side and bottom side are indicated with pencil marks. The sample is wrapped then in a way that the orientation can be recognized after opening the package. When investigating the soil fabric of samples which necessarily are taken in a wet condition, information ought to be obtained of the changes which may result from the drying-out process after sampling. Samples of wet soil materials and of soils which are too loose to keep their shape in fractions may be taken by metal cylinders. These may be made from canning tins (size No. 2), the bottoms and the covers of which are cut off. The cylinder is divided into smaller cans, each 2½ to 3 inches in height (fig. 37). The openings on each side are

closed by metal covers which are held together by a rubber band. In some cases it may be cheaper and more practical to have these cans manufactured specially. The soil is cut out by the cylinder and the sample number, soil type, location, horizon and orientation marked on the outside. Labels of tape are generally better than paper labels which in most cases become loose and drop off (fig. 38).

The samples taken in sample cans are stored in shallow drawers. It is advisable to open the can on the upper side without removing the rubber band. Samples of coherent soils taken in the form of fragments are kept in shallow paper boxes like rock samples and stored in the same way.

2. MICROBIOLOGICAL SAMPLING

Soil culture dishes. Samples for the purpose of preserving the soil life for laboratory observation or for the isolation of the organisms present in the soil spaces should be taken in sterilized glass dishes. A suitable sampling outfit consists of a cutting cylinder with a sharpened lower edge fitting into a slightly larger dish which is covered by a wider second dish. The cutting cylinder should not be larger than 20 mm. in diameter and not more than 50 mm. high. In the laboratory the cover can be kept in a raised position by means of small brick-shaped pieces of cork strung on rubber bands and held close to the wall of the lower vessel at any desired height. The raising of the cover makes possible a larger air space above the soil surface (fig. 39).

Sterile cutting of the soil samples with the glass cylinders may be performed by using special metal handles (fig. 40). Before every cutting the handles must be resterilized over an alcohol lamp.

Microculture dishes. A special type of small soil culture dishes was designed by the author and may be obtained from P. Haack, Vienna, under the name of microculture dishes. Since it is not necessary to open these dishes to make microscopic investigations on the surface of the soil, the chance of infection by microorganisms in the laboratory air is eliminated. To allow microscopic examination the upper plate of the microculture dish is of cover slip thinness (about 0.18 mm.) and optically perfect enough to allow undistorted observations of the soil spaces open to the surface. When the soil life in this space has reached a desired stage the cutting cylinder may be taken out and the observations continued in the interior of the

sample after removal and breaking of the soil mass. The window of the upper dish is fixed to the side walls with heat-proof and acid-proof cement.

3. SAMPLING FOR SPECIAL DECOMPOSITION STUDIES

For microscopic studies of the decomposition of different plant and animal residues or chemical preparations of organic compounds the following procedure allows decomposition processes similar to those found in the natural soil to become established in microscopic habitats. The method consists in mixing under sterile conditions a sample of soil in its natural moist condition with a definite amount of small particles of the desired organic substances. The soil with the organic additions is put into soil culture dishes from which the cutting cylinders have been removed. Although the original fabric of the soil has to be disturbed, the soil in the experimental dishes gradually grows into a new unit again under the influence of the physical, chemical and biological processes, quite in the same way as agricultural soil develops into a new unit and into a more or less compact body after its fabric has been disturbed repeatedly by tillage. The microbial life in the soil culture dishes starts under similar structural conditions as in the field soil loosened and prepared for seeding. The preparation of such experimental dishes is performed out in the field in order to get samples with natural moisture content and to include only the native organisms of the soil and the field air in the system. This is more difficult to establish when the manipulations and mixing are performed in the laboratory.

Culture dishes of pyrex glass may be obtained from Arthur Thomas Company, Philadelphia. The smaller (diameter 70 mm., height 50 mm., manufactured under the name "tanning dish, No. 4509") serves to hold the soil, the larger (diameter 80 mm., height 40 mm., trade name "crystallizing dish No. 4507") serves as the cover. The latter may be kept in raised or lowered position as desired during the experiment by means of cork pieces strung on rubber bands, in the same way as described previously. When lowered the cover permits to some degree a microscopic investigation of the soil spaces opening to the surface. Although only lower magnifications can be used, observations of the development of the microflora may be made to some extent without opening the dish. The space between cover and dish may be filled with a strip of cotton wadding.

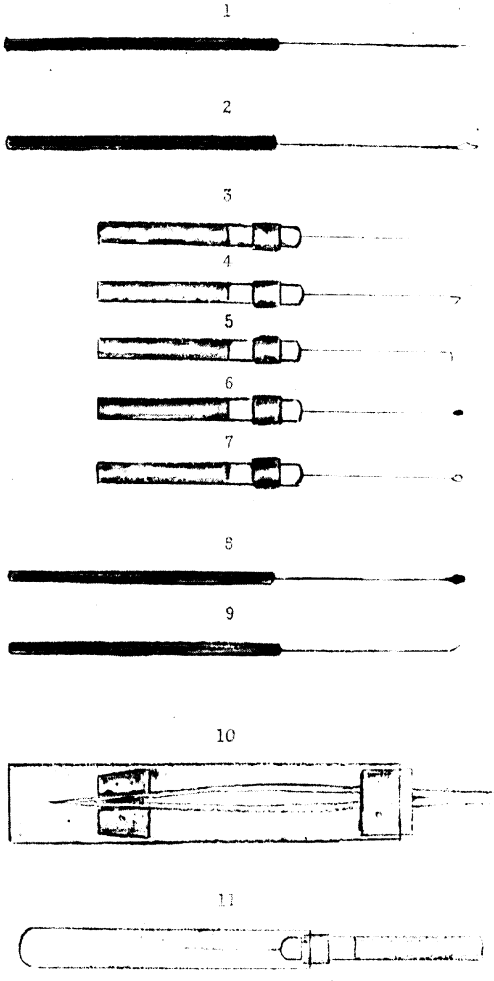


FIG. 21. Micro-tools. (1) micro-neeedle, (2) micro-lancet, (3) microplatinum wire, (4 and 5) hook-shaped platinum wires, (6) wire with flattened end, (7) platinum loop, (8) micro-spatula, (9) micro-spatula, side view, (10) micro-forceps in protecting glass, (11) microplatinum wire in micro-test tube.

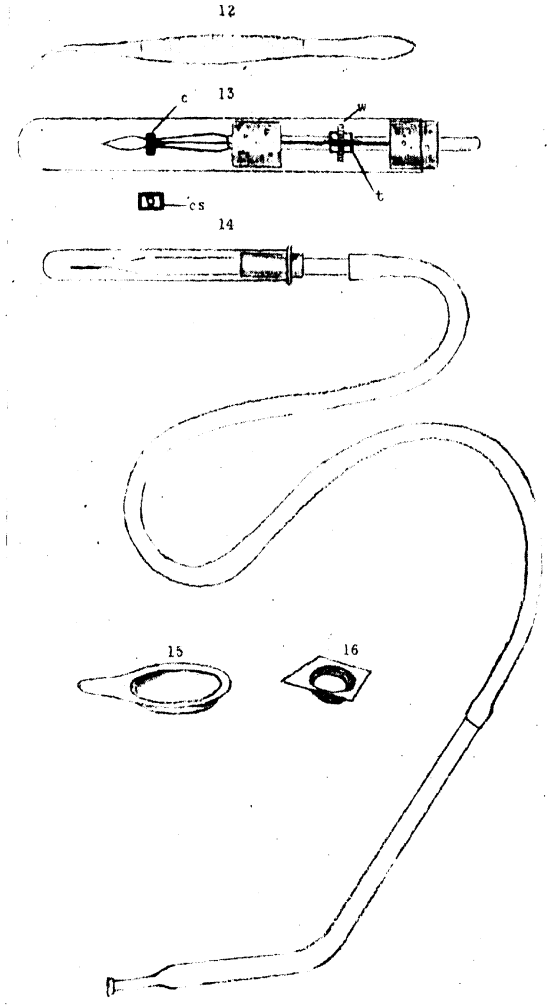


FIG. 22. Micro-tools. (12) micro-forceps (side view), (13) automatic micro-forceps (c, cs—metal collar, w—washer, t—threaded metal rod), (14) micropipette, (15) microplatinum spoon, (16) microplatinum dish.

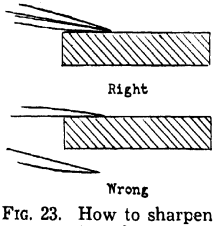


FIG. 23. How to sharpen

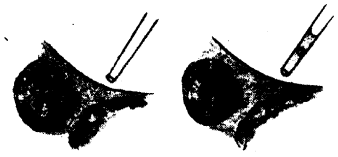


FIG. 24. Isolation of an object immersed in capillary water by a micropipette.

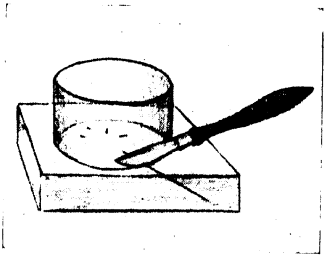


FIG. 25. Manufacturing of orientation needles.

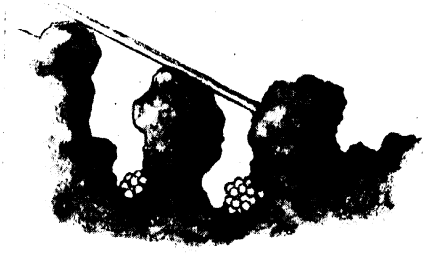


FIG. 26. Application of orientation needles at soil spaces containing sporangia of *Mucor glomerula*.

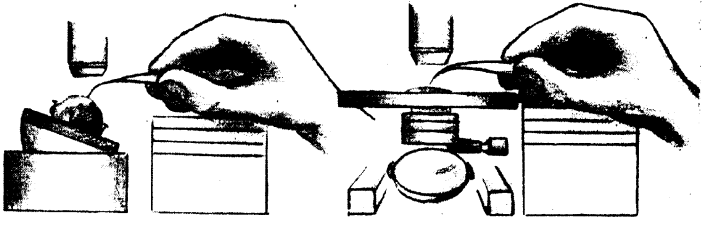


FIG. 27. Isolation with two microscopes.

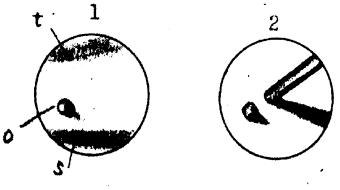


FIG. 28. How to bring the tip of a microtool into focus. (t) Indistinct picture of the tool, (s) shadow of the tool, (o) object.

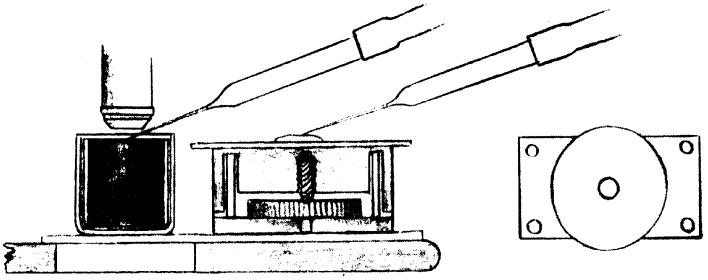
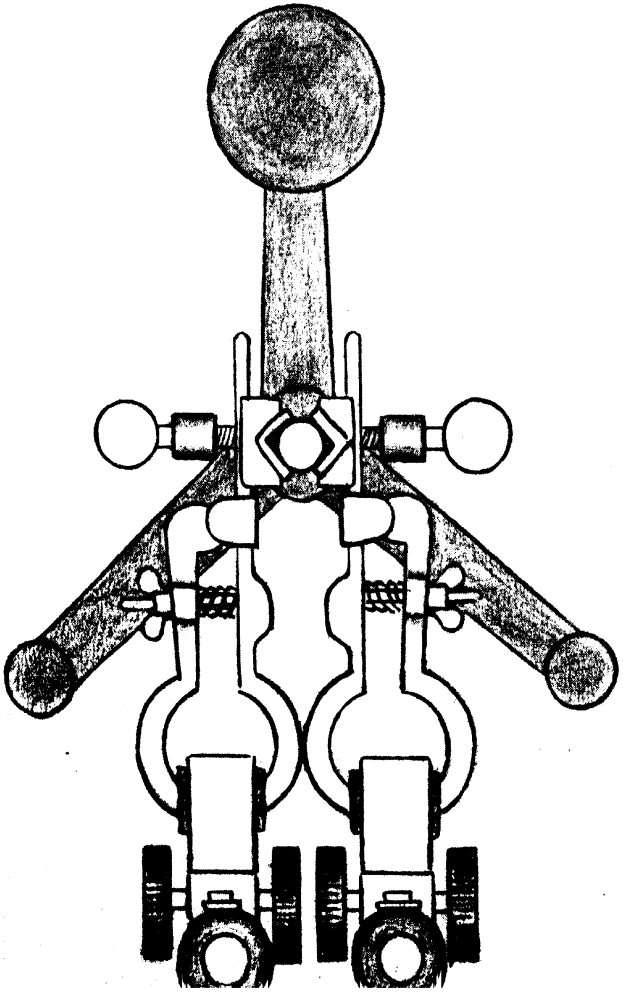


FIG. 29. Isolation with a single microscope and with an adjustable support for the slide.



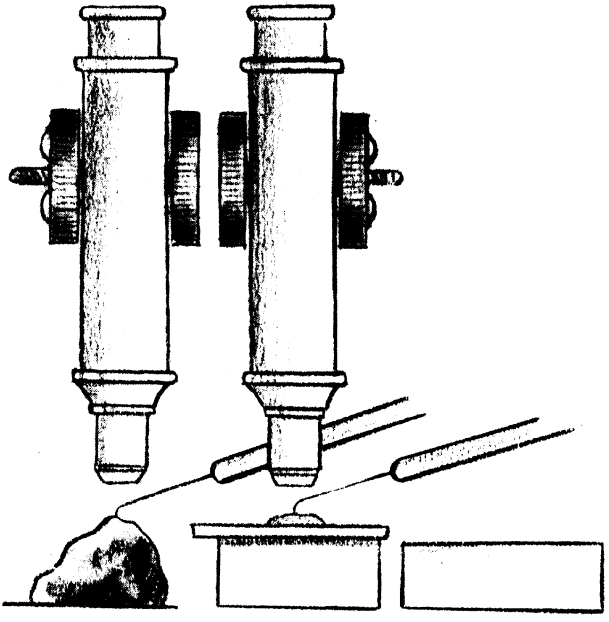


FIG. 31. Isolation with a double microscope (side view).

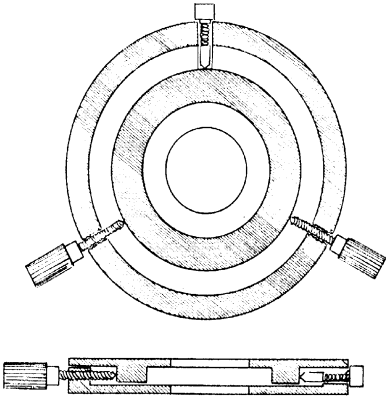


FIG. 32. Circular revolving microscope stage.

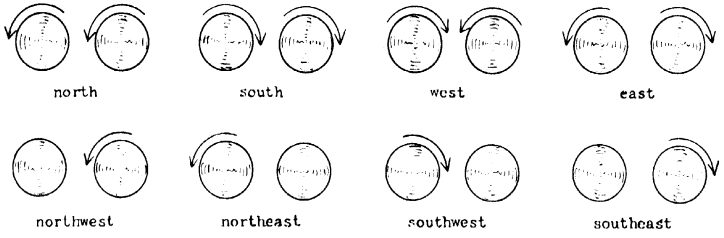


FIG. 33. Horizontal movements of the micromanipulator given by different turnings of the centering screws.

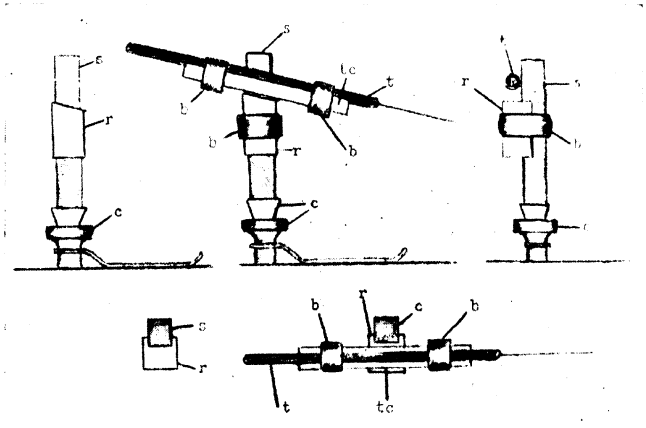


FIG. 34. Tool-holder of the manipulator. (tc) Tool clamp, (t) tool, (r) clamp rest, (b) rubber tubing, (s) shaft, (c) stage clip.

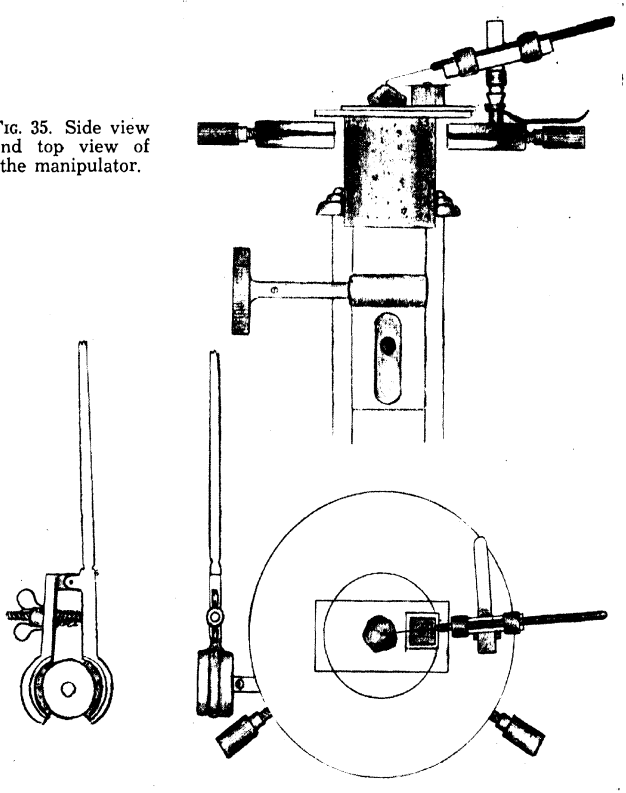


FIG. 35. Side view and top view of the manipulator.

FIG. 36. Oriented soil fragment labelled with tape pieces fixed on rubber band.

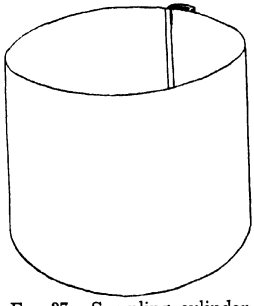


FIG. 37. Sampling cylinder.

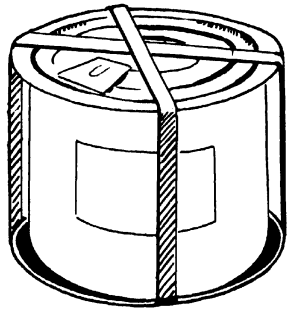


FIG. 38. Sampling cylinder with tape labels and metal lids held by rubber bands.

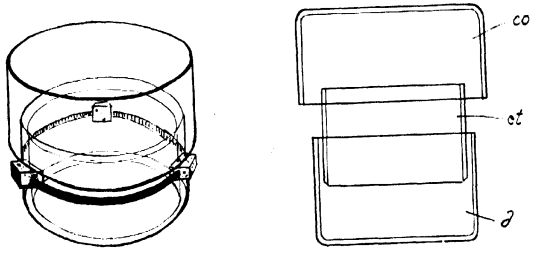


FIG. 39. Soil culture dish. (d) soil dish, (ct) cutting cylinder, (co) cover.

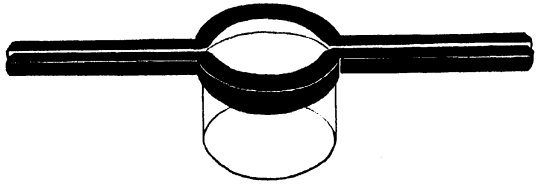


FIG. 40. Resterilizable metal handles with glass cylinder for microbiological sampling.

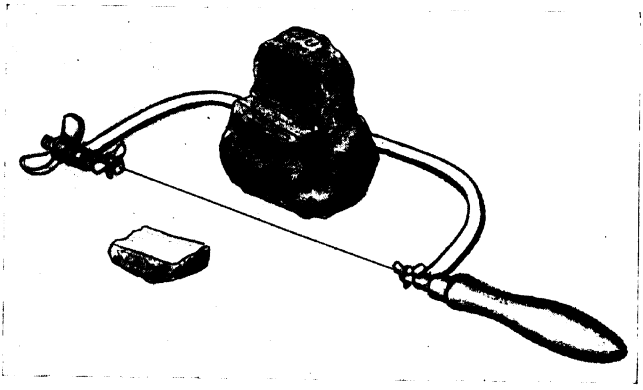


FIG. 41. Preparation of soil plates from oriented soil fragments with a watchmaker saw.

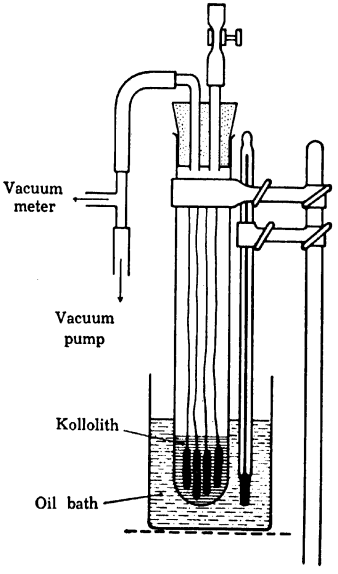


FIG. 42. Vacuum tube for impregnating soil specimens with kollolith.

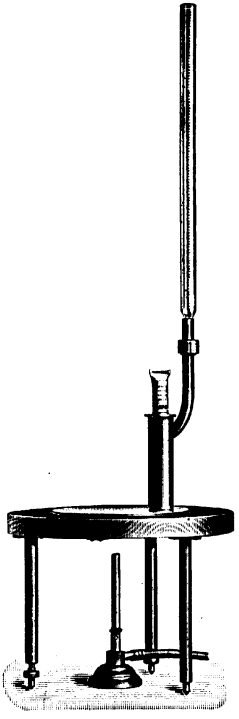


FIG. 43. Apparatus for mounting thin sections with kollolith (Voigt and Hochgesang).

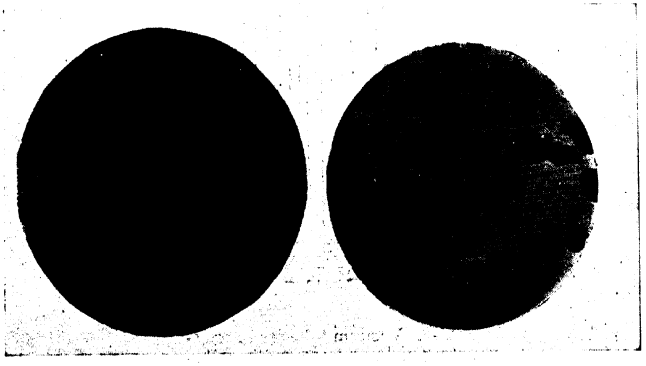


FIG. 44. Thin section of the B-horizon of a humus podsol near Bremen, Germany.

FIG. 45. Debris preparation of the soil in figure 44.

For the preparation of the soil samples under sterile conditions, sheets of water proof paper are unrolled from a sterile packet and spread on the ground. By means of a metal spoon, sterilized over an alcohol lamp, a clod of soil is taken, broken and crumbled. Then one of the glass dishes is unwrapped from its protecting paper, in which it was sterilized, and filled more or less loosely with soil. The remainder of the soil on the paper is discarded. After having determined thus the quantity of soil needed for filling the dish, the soil is emptied from the dish, placed on the paper again and mixed with the desired organic additions. Finally the dishes are filled once more with the mixture, covered and labeled. One series is left without additions as checks, and another sample may be taken with a cutting cylinder, so retaining its natural structure. Between every filling the working tools are cleaned and resterilized.

Determination of autochthonous and zymogenous flora. Every soil responds to the addition of organic residues or compounds in a typical way. The changes in the microbial life brought out by the additions are shown by the appearance of a number of new species which are characteristic for every soil. The organisms found in the soil without additions represent its autochthonous flora, whereas the organisms developing as a result of the additions are its zymogenous flora. By using different additions the method may be used for the determination of the different groups of the zymogenous flora. Of particular interest is the use of additions which are generally applied to a particular agricultural soil, such as farm manure (taken from the same farm), sweet clover, soybeans or other plants used as green manure, cornstalks, potato stems or other residues of plants. A combination of the soil culture method with the plate and dilution method will complete the results and allow the recognition of other species of microorganisms which are present only in the form of undeveloped spores.

4. SAMPLES OF SOIL CYLINDERS CONTAINING BURIED SLIDES

By the combination of the Rossi-Cholodny method with the direct microtechnical method of the author a working procedure is obtained which is particularly suitable for studies on the microbiology of the soil in the field.

Slides are buried at well marked places in the field and left in the soil for two or three weeks. It is advisable to bury one set in untreated soil and additional sets of slides together with additions of manure, fertilizers, green manure, etc., specifically

used in the management of the particular soil. The additions are cut up with sterilized scissors and buried in such a way that they are in contact with one side of the slide. After the time given above, cylinders of soil in an undisturbed condition are cut out with ordinary sampling cans (see p. 54), each containing one or two of the buried slides in its center. In the laboratory the samples are removed from the cans and broken (by the aid of an awl-shaped needle) in a plane traversing the front side of the slide. The broken planes are investigated with the soil microscope or another suitable incident light microscope, and after the observation the organisms found transferred to artificial media. Finally the slides are prepared, stained and examined for bacteria and other microorganisms. By the examination of the soil samples and slides, characteristic differences are found not only in the association of organisms but also in the rapidity of decomposition of organic additions.

CHAPTER VI

Soil Preparations

The reasons for making soil preparations are as follows:

1. To allow the preservation of microscopic soil parts of special interest for later examination with incident light.
2. To make unaltered soil parts transparent so that they may be investigated more in detail with high magnifications or with polarizing microscopes.
3. To make possible various treatments, staining reactions or microchemical analyses.
4. To investigate the arrangement and affinity of the fabric plasma to the fabric skeleton. (*See* chapter Soil Fabric).

To complete the direct microscopic investigations carried out both in the field and in the laboratory, three types of preparations are used: (1) the split preparation, (2) the thin section, and (3) the debris preparation.

1. SPLIT PREPARATION

(Reisspräparat)

Split preparations are made in order to preserve small soil parts of special interest, containing organisms or inanimate formations for later morphological investigations, studies of microhabitats and other purposes.

Soil parts containing microscopic formations of special interest found on the surface of a soil fragment obtained by splitting or breaking are brought to a small convenient shape by a needle or by a small watchmaker's saw. The preparation is fixed to a slide with fish glue and surrounded by a round or rectangular frame of cork slightly higher than the height of the soil fragment. It is covered then with a cover slip. Slide, cork frame and cover slip are mounted together by means of Canada balsam or fish glue.

Split preparations of greater fragility may be hardened by a drop of cellulose lacquer diluted in acetone. Soils which are not resistant to treatment with liquid reagents may be treated in the same way to make them more stable for staining reactions.

2. THIN SECTIONS

The principle of this kind of preparation consists in hardening a soil by special hardening substances and in grinding the concrete plate obtained to a thinness of 0.03 mm. for mineralogical investigations or from 0.05 to 0.07 mm. for fabric studies. In this process the natural fabric of the soil is preserved.

The making of thin sections of soils goes back to the first attempts of A. Delage and M. Lagatu in Paris in 1904 (20). Their sections, however, did not preserve the natural fabric. Crushed soil was mixed with the hardening substances and the paste obtained dried and ground.

Clarence D. Ross of Washington in 1923 described a method for successfully making thin sections of friable material without disturbing the natural fabric (21). Unfortunately, the periodicals containing the description of this method were not readily available and therefore were unknown to the author in Vienna. However, working independently, he developed a method similar to that of Ross. Details of his method will be given in addition to the following description of the method of C. S. Ross.

Method of C. S. Ross. Preparations of thin sections were made from sands, tuffs, arkoses, soils, plastic clays, shales and bentonites. Ross tried different binding and hardening substances for preparing the samples. At first bakelite and Canada balsam seemed most promising but later kollolith was found to be more expeditious and easily applicable.

A small electric hot plate, two slabs of plate glass, carborundum paper, carborundum, emery or alundum for grinding, a bottle of medicinal petroleum oil (nujol), alcohol, ether, acetone, xylol, slides and cover glasses comprise the materials needed. A revolving grinding plate is useful but not necessary, since the work can usually be done by hand. For clays, shales, bentonites, and carbonates the hand methods are usually superior to machine methods but materials containing quartz grind rather slowly by hand. When using kollolith (for sale by Voigt and Hochgesang, Göttingen, Germany) to treat sandy material, which takes the binder readily, the soil chip may be placed on the electric plate, the heat turned on and a fragment of hard kollolith placed on top of it. Another method is to place the chip face down in a small metal dish which contains melted kollolith. Capillary forces will cause the melted kollolith to penetrate throughout the specimen if the pores are large. After

heating in kollolith for 15 minutes the chip may be cooled and grinding begun. It rarely will be advisable to exceed temperatures of 150° to 170° C. The kollolith does not darken below 170° but darkens slowly at 200°.

In the case of fine grained materials kollolith dissolved in xylol has greater penetrating power. The xylol is driven off by the heat of the hot plate, but the hot kollolith xylol solution is mobile enough to penetrate all but the finest grained material with fair rapidity. The specimen must be heated at least an hour or more, the time of heating depending on the size of the soil chip and the degree of heat used.

Where it is advisable to heat the specimen as little as possible, it may be soaked in an ether-kollolith solution in a tightly closed receptacle for 24 hours or more, and afterward the excess solvent can be driven off by gentle heat.

The advantage of bakelite as a hardening substance lies in its ability to impart to a porous material greater coherence, toughness and hardness than can be obtained by any other material. Bakelite varnish manufactured by the Bakelite Corporation, Perth Amboy, New Jersey, is a syrup-like liquid that becomes a very hard, tough, resin-like material on the application of heat. The heating first drives off the solvents, but the real hardening depends on the condensation and results in an entirely new polymerized compound. To the bakelite varnish equal parts of methyl alcohol and ether are usually added.

It is best to keep bakelite varnish in a cool place since it gradually becomes darker and more viscous with age. In this form it does not easily dissolve in alcohol and ether, and forms a white curdy precipitate. Quick and complete solution can be obtained by the addition of a small proportion of acetone.

When using bakelite a dish with a tight cover is needed. The specimen is immersed in diluted bakelite varnish, covered and left for 24 hours. After the sample is removed a day or two is required for the solvent to evaporate. Then the final curing is accomplished by heating for two days at 70° to 100° centigrade. It is better to start at the lower temperature and after 5 to 12 hours increase it to 100°. A preliminary treatment may be necessary for very friable material to make possible the shaping of a suitable chip ready for the final impregnation with bakelite to fill the pores more completely.

A vacuum may aid in the impregnation of some materials

with unusually small capillary pores. The Bakelite Corporation manufactures a type of bakelite varnish and solvent expressly designed for vacuum impregnation. This special bakelite varnish together with the solvent is placed on the specimen in an air-tight container from which the air is then exhausted.

Soil plates which soften, swell or contain salts soluble in water are first ground with dry emery or carborundum paper. The thin section is then ground with oil on a large carborundum hone or the flat side of a fine-grained carborundum wheel and finished on a glass plate. Of the mineral oils nujol is the best liquid to use with the abrasive powder for grinding. When grinding on a revolving plate it is necessary to substitute kerosene for nujol to prevent the section from being jerked away from the fingers. In this case the section should be quickly finished to lessen the effect of the solvent action of kerosene on the kollolith and balsam. Although carborundum can be used for coarse grinding is not as suitable as emery prepared for optical work because its sharp grains which stick to the preparation are removed with difficulty.

Method of the author. From an oriented soil piece a plate about 2 to 3 cm. in diameter is cut out carefully with a watchmaker's saw. The plate should be sawed out as thin as possible without risk of breakage (fig. 41). If the soil is too fragile, a small soil piece is laid in a small dish containing a cellulose lacquer with about an equal volume of acetone. The plate is then dried and subsequently can be ground to a thinness of about 3 mm. The contours of the different plates ready for the hardening process are drawn in a notebook, the orientation marked (or the fact that the chip is cut out horizontally) and name, horizon and position in the profile noted. Then the plates are hung on thin flower wire and put into a vacuum test tube which contains about 15 g. solid kollolith. The test tube has a length of about 2.5 cm., a width of 3.5 cm. and is made of Jena or pyrex glass of a thickness of about 2 mm. The vacuum tube is mounted on a stand together with a metal dish containing an oil bath (paraffinum liquidum) and a 200° thermometer (fig. 42).

After the plates are put into the vacuum tube the apparatus is evacuated, then the oil bath continuously heated till the kollolith begins to foam. The plates will sink into the kollolith mass and take up the liquid. Foaming can be suppressed by gradually decreasing the vacuum. The plates are treated

from 10 to 30 minutes, according to the fineness of their capillary systems. In the case of very fine dispersed material the procedure may have to be repeated.

Grinding is started on an iron plate with carborundum (sizes 120 and 250), continued with fine emery on a glass plate and finished with finest emery paper. As grinding liquids, paraffinum liquidum and petroleum have been applied. Since, by microscopically controlling the hardness of the section with a micro-needle, the author found a considerable softening as a result of the application of liquids, their use has been completely avoided.

Microscopic control of the consistency of the section (testing with a micro-needle) showed a softening of the preparation by the warmth produced by the grinding process. In warm rooms and in the warm season the softening can be observed without mechanical testing by slight changes in the fabric and by interspersion of the preparation with carborundum grains or emery dust. The author prefers, therefore, especially in warm weather to work in a cool room and to carry out the later stages of the grinding on a glass plate placed over a box containing a mixture of ice and calcium chloride.

In earlier stages of the development of the method Canada balsam was also used in the same way as described by C. S. Ross, but partly diluted in xylol. Canada balsam cannot be substituted for kollolith in the vacuum tube because of its great inclination to foam. Likewise, other substances, such as cellulose lacquer (applied without heating), gave fairly good results after continuous impregnation of the chips. The result, however, is much inferior to kollolith.

Mounting soil plates and thin sections on slides. The procedure of mounting thin sections of soil on slides is the same as used in the preparation of thin sections of rocks. The hardened soil chip is ground on one side to a smooth plane. Then a piece of solid kollolith of the size of a pea grain is placed on a slide 28 x 48 x 1.2 mm. and melted over a microburner. In this step the formation of bubbles must be avoided. Bubbles may be removed by slightly touching the surface of the melted kollolith with the microflame. The plate with the smooth surface is placed on the melted kollolith and gently pressed onto it. Before the kollolith has congealed the worker should satisfy himself that no gas bubbles have formed between the chip and the slide. In this case the plate has to be taken off the

slide again, and this should be done directly only if the consistency of the kollolith permits easy and rapid removal. Otherwise, it is advisable to put the preparation with the glass side downwards on an ice cooled plate or on a piece of ice. After some time the plate may be easily removed from the slide with the finger nail or the point of a knife. The plate also has to be removed if the cementing has not taken place properly, as shown by the appearance of rainbow colors. The surface of the plate removed from the slide must be smoothed once more by grinding and the fixation must be repeated.

The mounting of soil plates on slides is facilitated by the pseudocumol thermostat of Voigt and Hochgesang (fig. 43). The apparatus consists of a hot plate which is combined with a metal cylinder filled with pseudocumol (boiling point 160° C.) and furnished with a long glass tube. The kollolith tube is placed in the cylinder and the hot plate gently heated as long as vapors of pseudocumol are developed in the glass tube and condense at about the halfway point. At this stage the kollolith has the best consistency for mounting. The kollolith tube is opened and a drop of the substance pressed on the slide which was heated on the hot plate. The mounting is performed on the wooden margin of the hot plate.

After the plate is mounted properly onto the slide it is ground on the other side until it becomes transparent. The final grinding must be performed under repeated control by the microscope. When the desired thinness is attained the preparation is cleaned by washing with petroleum, a small stiff brush being used. The effect of the cleaning is controlled by microscopic examination. Since emery and alundum powders have a great tendency to adhere to the preparation, especially if minute dents and grooves happened to be formed, this procedure must be performed with great care.

Finally a drop of ropy kollolith solution in xylol is placed on the clean preparation, and then a clean cover glass is gently pressed against it. The surplus kollolith on the margin of the cover slip is removed by pieces of folded paper, hard kollolith extending over the margin is taken off by a hot razor blade. Finally the preparation is cleaned with xylol and labeled. Marking the orientation of the thin section is especially important. It is advisable to orient the section on the slide in such a way that if cut out vertically the top side (up) is placed opposite the label.

General advice for thin section making. Since thin layers are more thoroughly impregnated with kollolith, the chip should be made as thin as possible. For the preparation a section close to the surface should be chosen in which the impregnation is better than in material taken from the interior, especially in the case of extremely dense material.

In many cases direct treatment by placing the soil plate in a small metal dish with melted kollolith, as described by C. S. Ross, will be sufficient to give satisfactory results. The procedure is simpler and allows considerable saving of kollolith. In the case of dense soils treatment in the vacuum tube, especially the evacuation of the plates before impregnation, is advisable. The vacuum tube will also help to lower the temperature which is important for the preservation of many soil constituents in unaltered state.

The use of a grinding machine is advisable only in the beginning of the grinding process. The final grinding should be performed always by hand. As to liquids used with the abrasives the author uses at present some nujol, as proposed by C. S. Ross for the very last stage of the finest grinding (used with alundum powder). As mentioned above, in warm weather the use of the ice box is indispensable when kollolith is used as the hardening substance.

Thin sections of aggregates. Soil aggregates or other soil complexes of a small size may be made into thin sections in the following way. A small paper frame of 20 mm. in length and 15 mm. in width is provided with a bottom of cheese cloth. The aggregates or soil fragments are put in it and the frame placed in a small metal dish with melted kollolith. After cooling, the plate thus produced is ground in the same way as an ordinary soil chip.

Importance of thin sections for soil investigations. The thin section shows details of the soil which could never be recognized by mere investigation of unprepared soils. This is made possible by the application of transparent light and highest magnifications to the soil in undisturbed condition. Furthermore, the thin section allows, as does the rock section, the identification of the mineral particles by optical methods.

In spite of these great possibilities the thin section can give us only a part of the information we need in order to get a real insight into the microscopic morphology, dynamics and biology of the soil. Since the soil in the thin section is not the living soil,

data on the biology and dynamics can be obtained only by reconstruction and not by observation. In order to get a conception of a house, its particular purpose and life, one has to see its interior as a whole. It would not serve very much to have only a thin plate cut out of it which shows only a cross section of it. A complete understanding of the cross section is possible only after a detailed knowledge of the three dimensional construction of the house and of all the objects which are within it. Hence, the pedologist will first have to investigate the soil spaces as such, and particularly the formations which are developed on the surface of their walls.

Although very useful information about the interior construction of the wall bodies and of compact soil masses can be obtained from thin sections, they are not suitable for the study of formations which occur on the surface of the different soil units. In thin sections the occurrence of soil colloids in the form of uniform coatings around the mineral grains could not be recognized. They would be visible only in the form of a dark line following the contours of the cross sections of the grains. Only in thicker sections would parts of the grain surfaces covered with the colloid layers be visible. (fig. 44). The coatings, however, become visible when the method of debris preparation is used (fig. 45).

3. DEBRIS PREPARATION
(Trümmerpräparat)

A little piece of dry soil of the size of a vetch seed is put on a slide and crushed by a wooden instrument such as the handle of a preparation needle. The crushing is performed in such a way that only the soil fragment is crushed and not the mineral grains of the soil. The debris is embedded in Canada balsam and covered with a cover slip.

The debris preparation is also useful in the study of the natural fabric of the soil. One might ask the question; how can one speak of the natural fabric of a crushed body? The soil can never be crushed to such an extent that a complete separation of all components is obtained. The soil may be divided into new units which are still complexes of its characteristic original construction. Since the complexes obtained are smaller and the elementary units and their arrangement becomes very apparent, the debris preparation permits us to get a good inside view of the construction of soil in smallest space.

Details are obtained which cannot be perceived by investigation of the unprepared soil.

Two kinds of detail observable in debris preparations are of particular interest. The first is the arrangement of soil particles on the surface of the mineral grains. They might be arranged in the form of more or less regular and uniform coatings. They might adhere to the bare grain surface at a few limited points, or they might not adhere at all. The second is the structure of the coatings or the localized grain deposits, the degree of affinity between the grain surfaces and the deposits, and the chemical nature of the different substances deposited on the grain surfaces.

CHAPTER VII

Fabric Reactions

The preparations mentioned in the previous chapter, which serve primarily for the study of soil fabrics, can be compared in some respects with the preparations used in histology or plant anatomy. Like the organic tissue the soil fabric consists of a number of components which differ in function and composition. These may be easy to distinguish in some cases by their appearance or in other cases they may be recognizable only with difficulty. In order to make them visible it is necessary to apply reagents which will react with only one of the components and not affect others. The reaction must produce a contrast in the appearance of a component without disturbing its shape and also without disturbing the natural arrangement of the rest of the fabric. The best methods for this purpose are staining reactions or reactions which take place on the surface of a given compound and are characterized by the production of strong color effects. Different treatments, such as charring or igniting, may affect the various components in a different way and therefore serve with similar advantages.

Fabric methods may be applied to all soil preparations if the treatments are not destructive to them. Thus, split preparations are suitable for staining only if the soil fabric is resistant enough to the reagents. Charring and igniting of materials to be used for sections must be done before impregnating the soil with hardening substances. The debris preparation is best suited for all kinds of fabric reactions.

Charring. Many organic subtances not contrasting in color may be visible by charring. The soil fragment or the soil debris is transferred to a microplatinum spoon or a microplatinum dish (the latter is better for microscopic investigation) or cover of a small platinum crucible and heated carefully until the organic substances are charred but not burned away. In this manner it is possible not only to show the presence of uncolored organic substances which may be present in a highly dispersed state in certain soil parts, but to contrast the mycelium of fungi and actinomyces.

Igniting. A small piece of soil is slightly crushed on a microplatinum spoon (microdish) and ignited. By this treatment all organic substances are burned, the hydroxides are dehydrated and the carbonates and lower oxides oxidized to higher oxides. The strong color of all colloids rich in iron compounds, thus transformed into ferric oxide, is in strong contrast to the color of the other components of the fabric. Many coatings of colloids contain ferrous compounds which are invisible until after ignition. Slight ignition is also necessary as a preliminary treatment before the application of the following staining reactions on inorganic colloids.

Reaction for electronegative colloids. To make electronegative inorganic colloids contrasting it is best to stain with basic aniline dyes. The best dye for microscopic purposes is malachite green. The slightly ignited soil debris is placed on a slide, and then a drop of malachite green dissolved in water is added. After half a minute excess stain is removed by small rolls of filter paper and the debris washed by the continuous adding of distilled water from a micropipette (microdropper with rubber tubing) and the removal of the liquid by filter rolls. The preparation is dried over a microburner and embedded in solid Canada balsam.

This reaction stains colloidal silicic acid and colloids rich in silicic acid an intense blue green. It does not stain quartz and the crystalline silicates, except mica and chlorite. The latter are stained because the malachite green solution penetrates into the clefts between the cleavage leaves from which it cannot be removed sufficiently by washing. The reaction leaves aluminum hydroxide and other electropositive inorganic colloids unstained.

The staining affinity of the malachite green for silica is not decreased after heating or slight ignition of the silica; in some cases even an increase of the staining intensity can be observed.

Reaction for electropositive colloids. Aluminum hydroxide (aluminum oxide), as well as electropositive colloids in general, can be stained by acid aniline dyes, among which congo red is the most suitable. In order to prevent a pseudo staining (caused by absorbed cations), the ignited debris is wetted with diluted hydrochloric acid and the suspension washed with distilled water several times. Then a drop of ammonia is added. After repeated washing the debris is heated over a microburner to remove the rest of the ammonia. Then the debris is transferred to a slide and treated with congo red solution

for about 5 minutes. The washing and preparation is performed in the same way as in the case of the malachite green reaction.

Among the electropositive inorganic colloids, iron hydroxide (iron oxide) is also stained by congo red. The coloration is generally less intense, and, because of the strong original color of the iron compounds, different in tint, being usually somewhat more yellowish. The use of aniline dyes for alumina is considerably less satisfactory than the use of malachite green for silica. In some cases, however, surprisingly good results may be obtained. The same procedure for removing absorbed cations, as described above, can be applied also before the treatment with malachite green in order to prevent pseudo staining.

Thenard's blue reaction. Colloids rich in alumina and free from iron compounds can be strikingly demonstrated by igniting with cobalt nitrate solution. The reaction was successfully applied by the author in the investigation of laterites.

The soil debris is placed on the microplatinum spoon and wetted with highly diluted cobalt nitrate solution. The solution is evaporated over a microburner, and then the microspoon is covered with a porcelain or platinum plate and ignited in the flame of a microburner. The parts consisting of alumina or colloids rich in alumina become visible by their intense blue color caused by the production of cobalt aluminate ($Co(AlO_2)_2$). The reaction is disturbed, however, if aluminum oxide is present in a mixture with iron compounds. The cobalt nitrate reacts with the iron oxides and produces black precipitates. Black deposits on the bottom of the platinum spoon are produced from surplus cobalt nitrate also, even in the absence of iron compounds. It consists of cobaltocobaltic oxide and is easily removed by dilute hydrochloric acid.

Sometimes silica and silicates may give an intense blue color by ignition with cobalt nitrate. It is produced at the temperature of fusion and caused by the production of cobalt glass. The coloration, however, is different in tint and appearance, and generally the surface of the cobalt glass shows the typical glass shine.

Removal of free iron oxide. In some cases the Thenard's blue reaction may be possible in colloid mixtures containing iron after removal of the iron compounds by the method of Drosdoff and Truog. The removal of free ferric oxide can be performed by introducing hydrogen sulfide into a water suspension of the soil debris in a micro-test tube.

After some minutes a trace of ammonia is added, the test tube closed by a rubber stopper and left for half an hour, being shaken from time to time. The suspension is filtered and the residue treated with 0.1 N. hydrochloric acid for a few minutes. Then the suspension is again filtered and washed several times. The reaction is somewhat complicated because of the irritating sulfur residues. They must be removed by washing with 95 per cent ethyl alcohol (to remove water) followed by treatment with a solution consisting of one volume of carbon bisulfide and two volumes of 95 per cent alcohol (to remove the sulfur). Finally the residue is again washed with alcohol (to remove the carbon bisulfide).

Reaction for iron oxides. Ferric oxide, ferric hydroxide and ferrous compounds (which are oxidized by ignition) can be made apparent by adding a drop of potassium ferrocyanide to the preparation. The reaction takes place only after the addition of some dilute hydrochloric acid since the mentioned iron compounds are not soluble in water. The slow action makes the reagent one of the most perfect for treating fabric preparations, since the finest structures produced by iron colloids become visible with great exactness. The presence of larger amounts of colloidal silica may slow down the reaction to a great extent so that one or two days may be necessary for its completion.

Reaction for calcium carbonate. To show up constituents consisting of calcium carbonate in the soil fabric some of the so-called Lemberg reactions may be applied. The best for this purpose is the aluminum chloride Campeachy-wood reagent with which an intense violet coloration is produced by calcium carbonate. Magnesium carbonate shows almost no reaction; aluminum hydroxide gives a pale violet color. The reagent is prepared by dissolving 4 parts of aluminum chloride in 60 parts of water, and by addition of 6 parts of Campeachy-wood which has to be boiled in the solution for 25 minutes, after which the extract is filtered.

For the staining of calcium carbonate a drop of the reagent is added to the soil preparation and removed by rolls of filter paper. After treatment the preparation is washed and dried.

CHAPTER VIII

Optical Methods

1. DETERMINATION OF THE REFRACTIVE INDICES OF SKELETAL MINERAL GRAINS

If a mineral grain is embedded in a transparent medium with a different index of refraction the grain will be clearly visible. The marginal contours are visible in the form of strong black lines caused by total reflection of the light rays entering the microscopic preparation from the lighting apparatus of the substage. The darkness and width of the contours of a soil particle increase with the difference between the index of refraction of the particle and that of the embedding medium. In the case of equal indices the dark marginal contours disappear. If the soil mineral or soil colloid shows the same color and structure as the embedding medium it becomes entirely invisible.

Soil thin sections, which are manufactured without or with only slight application of liquids in the grinding process (in order to avoid the softening of the colloids), show generally a somewhat rougher surface than thin sections of hard rocks as produced by the procedure commonly used in petrography. The rough surface is especially clear and contrasting if the soil particle and embedding substance differ greatly in their refraction indices. They are barely visible, however, or disappear entirely, if the indices are the same or almost the same.

Furthermore, particles with high refractive indices show a bright line on the inside of the marginal contour which makes them appear higher than their environment. On the other hand, particles with refractive indices lower than the index of the embedding substance show a bright line at the outside of their marginal contours which makes them appear almost as holes in the preparation or at least as depressions in the surface relief.

If kollolith with a refractive index of $n = 1.535$ is used as the hardening and embedding substance, the appearance of the sections will vary according to the following possibilities for skeletal mineral grains with different indices of refraction:

Grains of titanite or zircon will show their rough surfaces even if the condenser of the microscope substage is raised to its highest position. The refractive index of these constituents is 2.0 or more. If the microscope condenser is in a half lowered position, then the surface relief of grains of hornblende, augite, tourmaline and other minerals of refractive indices between 1.6 and 1.7 will become clearly visible. The rough surface of peptized binding substances rich in peptized humic substances and alumina and of minerals like muscovite, showing an approximate refraction of $n = 1.55 - 1.6$, will appear if the condenser is entirely lowered. The bright line in this case will appear at the outside of the marginal contour, especially when the tube of the microscope is lowered. In the case of binding substances the investigation is best performed on parts of the margin of the preparation or in parts bounding soil spaces. The phenomenon will be observed with peptized silica or colloids extremely rich in silica, also with minerals such as orthoclase, microcline, gypsum, and, to a great extent, also calcite and dolomite.

The phenomenon will be entirely different if bakelite is used as the hardening substance because only very few constituents show a higher refractive index than this embedding substance.

The immersion method. Debris preparations may be used for the determination of the refractive indices of soil particles if different immersion liquids of known refractive indices are applied instead of Canada balsam or kollolith. The method, developed originally in petrography, was introduced by F. Steinriede in the earliest stages of the mineralogical investigation of soil (23).

An exact determination of the index of refraction will generally be necessary only in very rare cases in soil investigation. It is usually sufficient to estimate the refraction within certain boundaries. This can be performed with a few immersion liquids which are selected according to the soil constituents suspected. A list of immersion liquids with their refractive indices is given in fig. 48. Sometimes the removal of colloid coatings on the mineral grains by very dilute acids and alkalies may be necessary.

The soil debris is embedded in the immersion liquid and covered with a small cover slip of about 8 x 8 mm. in size. It is advisable to start with a liquid of low refractive index and to replace it gradually by those of higher refraction. For the change of the immersion medium the liquid under the cover slip is sucked out by small rolls of filter paper; the preparation

is washed by placing a drop of xylol to the edge of the cover slip, and the washing continued by several drops of the following liquid of higher refractive index.

The determination is best performed with the diaphragm of the lighting apparatus closed to a small opening. At the same time objectives not too low in magnification should be used (45x and more, depending on the size of the constituents to be determined). In order to recognize whether the refraction index of the soil constituent is lower or higher than the immersion liquid three different methods may be used:

1. *Method of F. Becke.* The object is focused at its marginal contour. If the microscope tube is raised or lowered with the fine adjustment, a bright line will migrate then into the interior of the questioned soil particle or outside into the immersion liquid (Becke line, see also p. 82). The bright line will always move into the higher refractive substance if the tube is ~~lowered~~ raised (fig. 46). The wider the difference in refraction between the soil constituent and the immersion liquid, the clearer is the Becke line.

2. *Method of A. Brun.* By raising the microscope tube the center of the soil constituent becomes brighter if its refractive index is higher, or darker if its refractive index is lower than the immersion liquid.

3. *Method of J. L. Schroeder van der Kolk.* For this method a low power objective is used. The diaphragm is contracted as well or the substage condenser lowered. With a piece of black cardboard placed between the microscope mirror and the condenser the light beams are screened on one side. The margin of the soil particle will appear bright on one side and dark on the other. If the bright margin appears on the same side on which the screening is performed then the soil particle is lower in refraction than the immersion liquid. The refractive index is greater if the bright margin appears at the opposite side (fig. 47).

For the determination of the mineral grains of the soil it is most advisable to use clove oil as the first and lowest refractive immersion medium. Orthoclase, microcline and gypsum (sometimes also calcite and dolomite) will then have a smaller refractive index. Calcite and dolomite have a wide range of refraction. Only the lowest indices will be smaller than the index of the clove oil, the higher extending beyond the refractive index of bakelite, as indicated in fig. 48. The feldspars are easily recognized by their perfect cleavage, which in some cases may

be observed also in gypsum. Calcites appear in the form of grains or in special cases of rod-shaped crystals or rhombohedrons and in the form of needles.

The soil debris might be immersed then in the liquids given in fig. 48. In addition to the refraction the color and appearance of the minerals aid in their identification as given in tables I and II. Only isometrically crystallizing minerals show one and the same refractive index in every direction of the crystal, while in minerals crystallizing in other systems the refraction varies in different directions. Crystals belonging to the hexagonal and tetragonal systems have two directions of different refraction; those belonging to the orthorhombic, monoclinic and triclinic systems have three. Different sections of these minerals may show any index between the highest and lowest refractive index.

For the investigation of the mineral grains in thin sections the determination of other optical properties comes into prominence as will be discussed in the following paragraph.

2. INVESTIGATIONS WITH THE POLARIZING MICROSCOPE

The polarizing microscope is an instrument for transmitted light which contains two polarizing calcite prisms (Nicol prisms), the polarizer, (in the substage) and the analyzer (in the tube of the microscope). Other accessories are given in fig. 49. Details of the theory and the construction of such instruments as well as of the working methods can be taken from any text book on mineralogy or petrography (24, 25, 26).

The most important optical properties for soil investigations which can be determined with the polarizing microscope are: Isotropy or birefringence, height of birefringence, pleochroism, extinction, type of axial figure and character of double refraction. Since the requirements of the investigation of soils are different from those of petrography, a certain simplification in the application of the methods is possible.

Birefringence. As indicated in the previous paragraph some minerals show the same refractive index in every direction of the crystal; they are singly refractive or isotropic. These minerals either are amorphous or crystallize in the isometric system.

Minerals belonging to other systems show different refractions in different directions. The light ray entering the crystal from the substage of the microscope is generally divided into two rays showing different velocities of movement vibrating in

planes practically vertical with respect to each other. The crystals of this type are called doubly refractive or birefringent.

In some cases in one direction of the crystal (the optical axis) no birefringence can be observed. The minerals having this property, namely those which crystallize in the tetragonal, hexagonal system, are uniaxial. The two light rays of different refractions are called the ordinary ray (o) and the extraordinary ray (e). The symbols of their refractive indices are ω and ε. In the case of a calcite rhombohedron the ordinary ray vibrates parallel to the long diagonals of the rhombic faces and at right angles to the optical axis and the extraordinary ray in a plane passing through the short diagonal and the optical axis.

Not only are the values of ω and ε very characteristic for different minerals, but also the value $(\varepsilon - \omega)$ called the height of birefringence. In some minerals the velocity of the extraordinary ray is faster than that of the ordinary ray, and in others slower which is indicated by their indices of refraction. In the first case ε is greater than ω, therefore $\varepsilon - \omega$ is positive. In the second case ε is smaller than ω, therefore $\varepsilon - \omega$ is negative. The first group of minerals represents positive crystals or such with + character, the second such with — character.

The doubly refractive crystals of the orthorhombic, monoclinic and triclinic systems have two directions in which no birefringence is noticed. They are biaxial. In the case of biaxial crystals three characteristic indices of refraction are observed. The smallest is designated as α, the greatest as γ, the medium β. The index β which indicates the refraction of light traveling along an optic axis is constant. The value $\gamma - \alpha$ represents the height of birefringence. If $\gamma - \beta$ is greater than $\beta - \alpha$, then the character of birefringence is positive.

Determination of birefringence. The determination is performed with parallel polarized light (obtained by removal of the upper lens of the condenser) and crossed Nicol prisms. The singly refractive or isotropic minerals placed between crossed Nicols remain dark on rotation of the microscopic stage. The double refractive or anistropic minerals become alternately dark and bright (unless they are cut or placed at a right angle to an optical axis). Sometimes the birefringence is very feeble. In this case it may be recognized by inserting a gypsum plate (selenite plate) between the objective and the analyzer.

A doubly refractive mineral placed between crossed Nicols, in a position which does not lead to total extinction of light, exhibits characteristic interference colors. These colors vary

primarily with the thickness of the thin section, the kind of mineral and the direction in which the mineral was cut. Since most of the mineral grains of the soil consist of quartz, the interference colors make it possible to estimate readily the thinness of the section. Since different degrees of thinness are desired for the different types of examination made by use of the thin section, the property is particularly helpful in the course of their preparation. Thin sections for mineralogical investigations should be ground down to 0.03 mm. (standard thinness), those for fabric analyses only to about 0.05 to 0.07 mm. Figure 50 gives the interference colors of quartz in sections of different thickness. According to this diagram the larger quartz grains of soil sections for mineralogical investigations should appear light yellow, and those of soil sections for fabric analyses red-orange to blue-violet.

The height of birefringence, i. e., the difference between the greatest and the smallest index of refraction ($\varepsilon - \omega$, $\gamma - \alpha$) is determined in two different ways. The first method consists of the direct determination of ω and ε or α and γ. The second method serves for an approximate determination and is based upon the observation of the interference colors. Since an approximate determination is sufficient for soil investigations the first method can be dispensed with and the second method simplified by direct reading of the birefringence on the color chart (fig. 51).

For this purpose the approximate thickness of the mineral grain (in the case of loose grains) or of its thin section is measured by means of the micrometer screw (fine adjustment). One interval of the micrometer screw usually represents 0.001 mm., on student microscopes 0.002 mm. The microscope is focused upon a point of the upper plane of the mineral (scratch in the surface or dust particle) then on a point of the lower plane and the movement of the microscope tube measured by means of the scale of the micrometer. This figure is not the real thickness which is then obtained after multiplying the reading by the middle value of the refractive index of the mineral suspected. The latter is either $\frac{2\omega + \varepsilon}{3}$ or $\frac{\alpha + \beta + \gamma}{3}$ (the refractive indices of different minerals are contained in fig. 48, and the tables I and II). In many cases, an

estimation of the thickness of the section from the interference colors of the neighboring quartz grains will be sufficient. From the thickness of a mineral and its interference color the birefringence may be obtained from the color chart in fig. 51, in which the change of interference colors of different minerals is pictured in a similar way as in the case of quartz in fig. 50. The colors of the different orders vary markedly in intensity and can be easily distinguished, the colors of the first order being dark and intensive, those of the third order light and almost whitish.

Pleochroism. Pleochroism is recognized by the appearance of differences in color when the microscope stage is rotated with the polarizer inserted and the analyzer removed. Some minerals can be influenced artificially to show pleochroism by ignition, especially those containing iron compounds. Hornblendes have a stronger pleochroism than augites. They show also a stronger increase of pleochroism when ignited. Pleochroism is also characteristic for dark colored epidot and partly for chlorite.

Extinction. If a mineral shows clear cleavage lines or crystal boundaries, then the kind of extinction can be observed or the angles of extinction measured. The latter is performed by means of the cross hair eyepiece and the graduation on the margin of the microscope stage. Before the determination, the optical axis of the microscope is centered by means of the centering screws of the objective (the same rectification must also be carefully made for the observation of the interference figures described in the following paragraph. A mineral shows parallel extinction if the cleavage lines or crystal boundaries are parallel with one of the lines of the cross hair in the position of extinction. If, at this position, an angle is formed between the two, then the extinction is inclined or oblique. Parallel extinction is observed with tetragonal. hexagonal and orthorhombic minerals. Monoclinic minerals show only parallel extinction perpendicular to the plane of symmetry; triclinic crystals always have oblique extinction.

Observation of the interference figure. In order to obtain interference figures the condenser lens above the polarizer is inserted, i. e., the observation performed in conoscopic light in contrast to the investigations noted above which are made in orthoscopic light. The Nicol prisms are kept in crossed position, the eyepiece either is removed or compensated for by insertion of a Bertrand lens into the microscope tube (fig. 49)

by which the image of the interference figure is focused on the focal spot of the eyepiece. For conoscopic observations a medium to high power objective should be used; for the investigation of thin sections most preferably a 4 mm. objective (45x). The use of a diaphragm close to the polarizer is helpful in obtaining a clearer picture.

The interference figure of uniaxial crystals when viewed in the direction of the optical axis is a dark cross (fig. 52). In sections inclined to the optical axis the center of the dark cross is moved sideways. In very inclined sections it is not visible in the microscope field. In this case only one of the arms of the cross will be seen. Some eccentric positions are pictured in fig. 52. If the center of the axial cross is seen in the center of the microscopic field, then the interference figure does not change when the stage of the microscope is rotated. However, the center of the axial cross rotates around the center of the microscopic field (intersection of the two filaments of the cross hair eyepiece) if its position is eccentric. During the rotation the arms of the cross remain always parallel to the filaments of the cross hair. For the observation of the character of the birefringence it is essential to know in which direction the center of the axial cross, not visible in the microscopic field, is situated. One end of the visible arm of the cross is moving in the same direction as the microscope stage, the other end in the opposite direction. The center of the axial cross is always situated at the end moving in the same direction as the stage.

In addition to the dark cross, in many cases a number of colored concentric rings will be visible. The number of rings is increased with the thickness of the section and with the height of birefringence.

The typical interference figure of biaxial crystals consists of two black curves, the so-called isogyres (fig. 53). By rotation of the crystal with the microscope stage the curvature of the isogyres is changed and also their position, forming a temporary cross only in the position of extinction. Both isogyres remain in the microscopic field. Instead of the circular color rings observed with uniaxial pictures each isogyre shows a set of more or less elliptical rings which merge in the center of the field between the isogyres. In the case of inclined sections which are cut at a right angle to one of the optical axes only one of the isogyres is visible (fig. 53, positions 3 and 4).

Character of birefringence. The optical character is deter-

mined by insertion of a gypsum plate, showing the red of the first order in polarized light, between the objective and the analyzer. By the insertion of the gypsum the appearance of different colors in the interference figure is noticed.

In the case of uniaxial crystals the interference colors in the quadrants formed by the arms of the axial cross are observed, especially in the parts close to the intersection of the cross arms. A negative character is deduced if in the northwestern and southeastern quadrant a blue color appears (fig. 54). Yellow color in the intersection angles of the same quadrants indicates a positive character. The optical character also can be determined if only one arm of the axial cross is visible. It is only necessary to determine the position of the intersection point of the cross by rotating the microscope stage as described in the previous paragraph.

In order to determine the optical character of biaxial crystals the two isogyres are brought into a position from northwest to southeast (fig. 54). A blue color on the convex sides of the isogyres indicates negative character; yellow color, positive character. The determination is performed in the same way if only one of the isogyres is visible in the microscopic field.

Major characteristics of different minerals. Quartz is easily recognized by its great preponderance in every soil thin section (with the exception of a very few special cases). The worker soon becomes familiar with its appearance and its interference colors. It is well characterized by its uniaxial interference figure and its positive optical character. The only other uniaxial mineral of importance, calcite, shows very high birefringence, characterized by almost whitish interference colors. Its optical character is negative. While quartz represents the major skeleton mineral, calcite is found in the skeleton of the soil only in special cases because of its great instability in regard to weathering. Thus, calcite or dolomite grains are characteristic for the humus layers of rendzina soils and certain red earths. The second most important skeleton mineral, muscovite, is biaxial with high birefringence and negative optical character. Its occurrence in colorless laminated plates and scales makes its recognition easy. Biotite is generally observed in brown or brownish-green plates or scales in the soil, chlorite in intense green plates. Both are biaxial and have a very small axial angle (sometimes even 0°) i. e., the isogyres of the interference figure are very close to each other. Pleochroism is more marked in chlorite

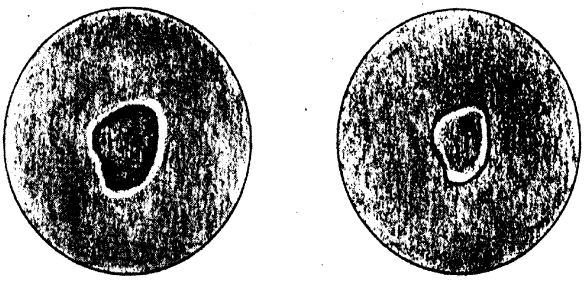


FIG. 46. Becke-line by lowered (left) and by raised (right) microscope tube. The immersed mineral is greater in refraction than the immersion medium.

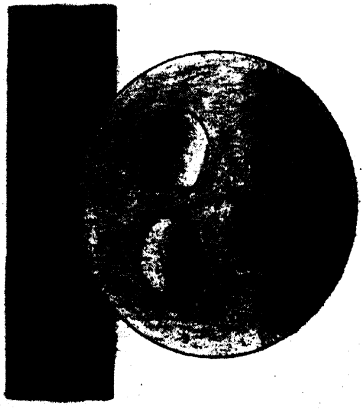


FIG. 47. Schroeder-method. Upper grain, greater, lower grain, lower in refraction than the immersion medium.

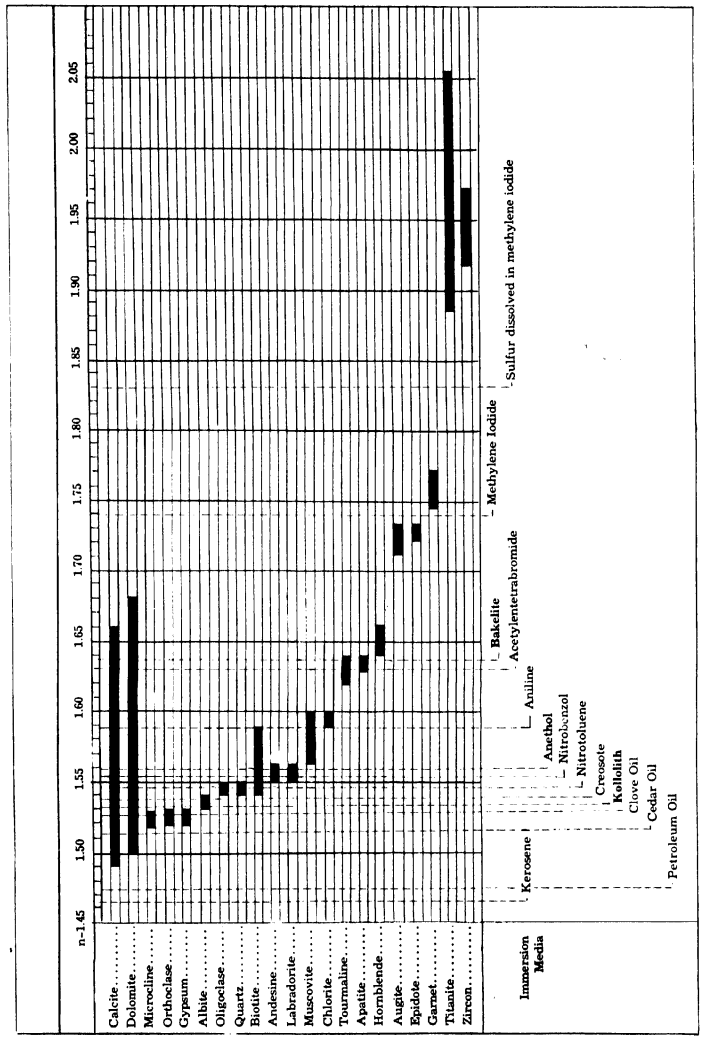


FIG. 48. Refractive indices of skeletal minerals.

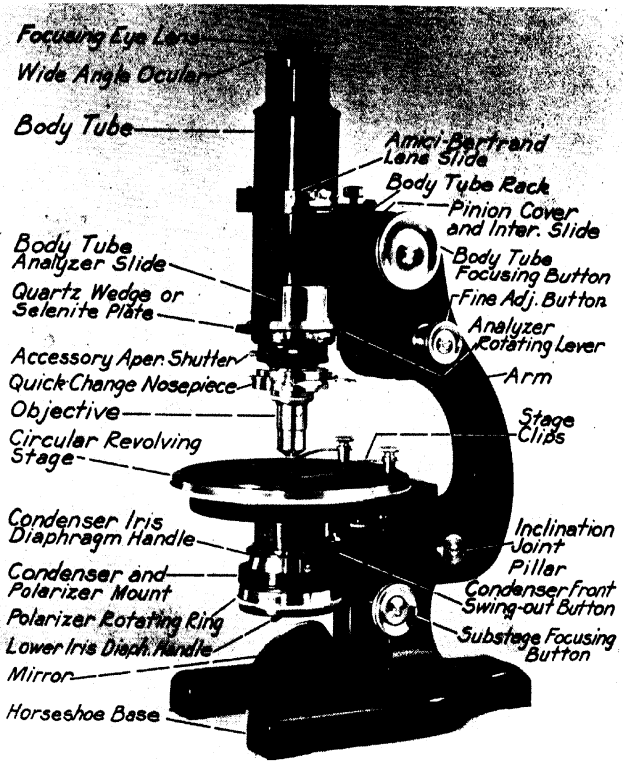


FIG. 49. Polarizing microscope (Spencer).

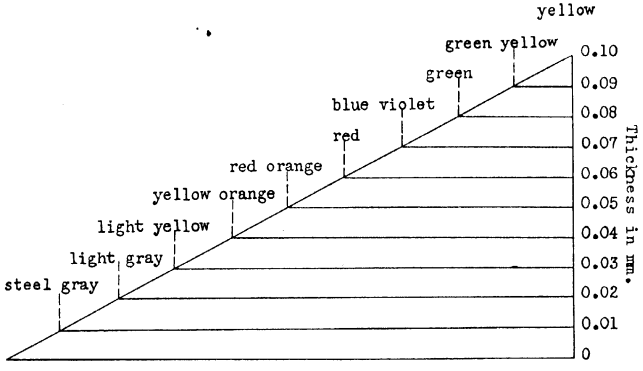


FIG. 50. Change of interference colors of quartz with increasing thickness between crossed Nicols.

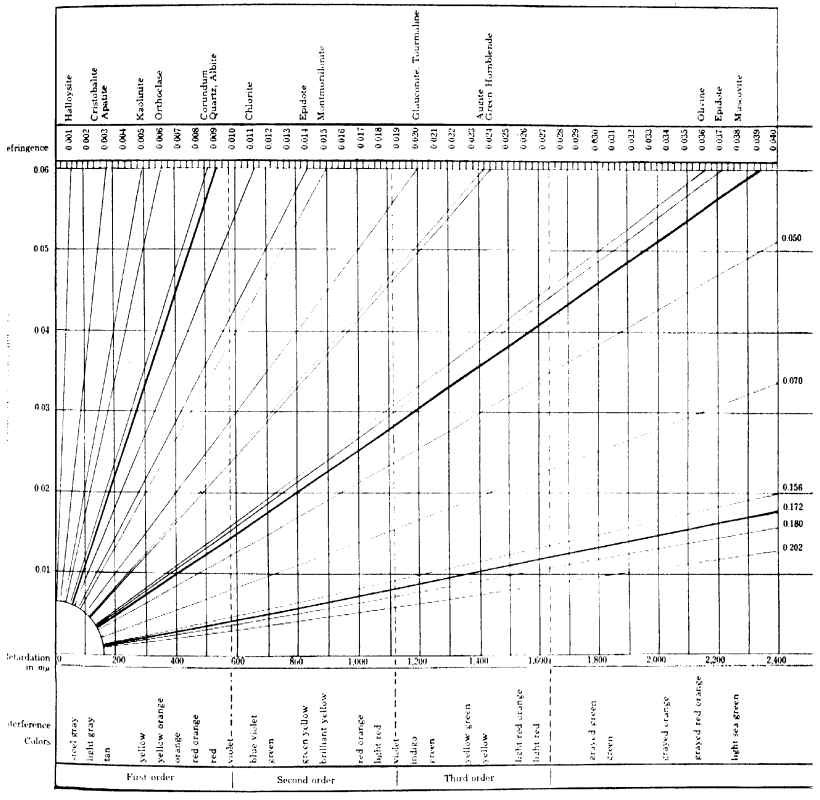


FIG. 51. Chart of interference colors.

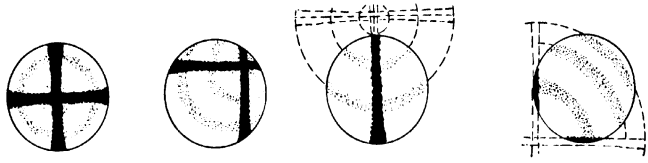


FIG. 52. Some interference figures of uniaxial crystals.

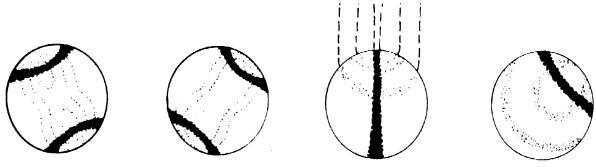


FIG. 53. Some interference figures of biaxial crystals.

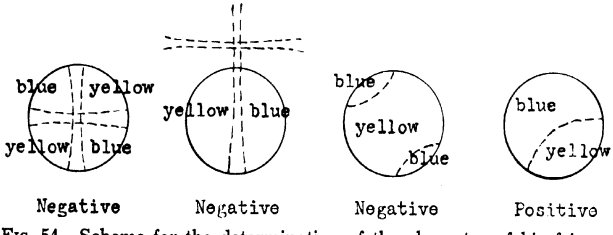


FIG. 54. Scheme for the determination of the character of birefringence.

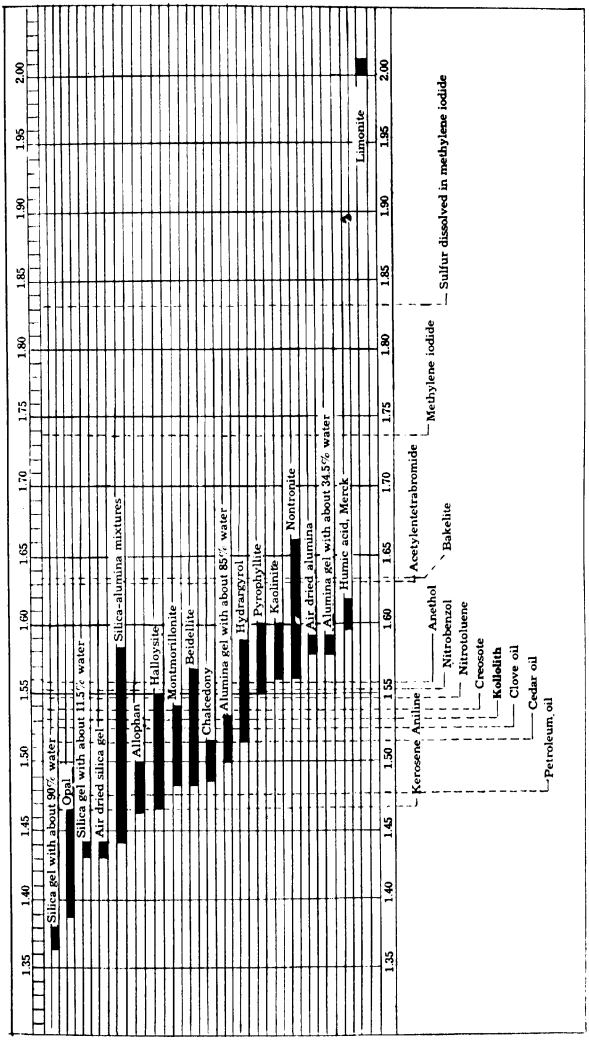


FIG. 55. Refractive indices of the most important colloid gels and clay minerals of the soil.

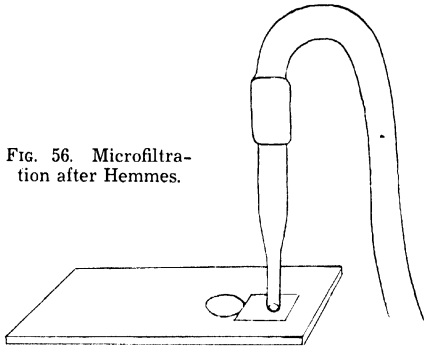


FIG. 56. Microfiltration after Hemmes.

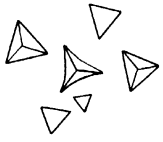


FIG. 57. Sodium uranylacetate.

FIG. 58. Bismuth nitrate.

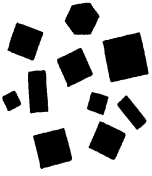


FIG. 59. Potassium copper lead nitrate.

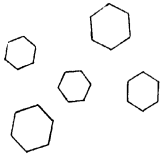


FIG. 60. Potassium bismuth sulfate.

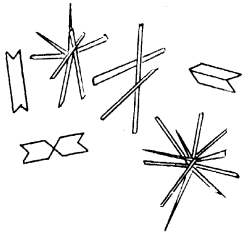


FIG. 61. Calcium sulfate.

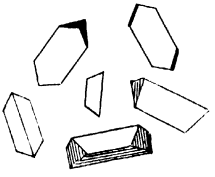


FIG. 62. Calcium tartrate.

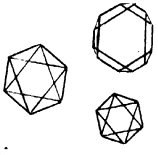


FIG. 63. Cesium alum.

FIG. 64. Silver chloride.

when plates are cut across the laminae. Otherwise, pleochroism is rarely visible. Chlorites frequently show positive optical character; biotite is always negative. The biaxial feldspars are characterized by their typical cleavage. The plagioclases are usually distinguished from orthoclase by their characteristic twin lamellae. Orthoclase shows negative; albite, andesine and labradorite, positive, optical character. Albite and oligoclase on the one hand and anorthite (negative) on the other are distinguished by their different refractions. Anorthite is rarely found in soils. Microcline, a feldspar of the composition of orthoclase which accumulates in some soils, shows, between crossed Nicols, very typical spindle-shaped twin lamellae which cross each other at right angles (so-called gridiron or quadrille structure). Gypsum is rarely found in the skeleton and is easily recognized as an authigenic mineral by its appearance and its position in the fabric (*see* Part II of this book). Hornblendes are distinguished from augite by their much greater pleochroism and their negative optical character. Augites are much less frequent in soil because they are much more open to weathering. Epidote is mostly characterized by its yellow-green color. Prismatic epidotes usually show parallel striation.

General remarks. The mineral grains which can be determined in the thin section represent the skeleton of the soil fabric. Their detailed determination is, therefore, of minor importance. In all soils those minerals which are most resistant to weathering are accumulated. The degree of resistance to weathering varies considerably in different soil types. The variety of minerals in the skeleton of a given soil is, therefore, a criterion of the soil type. Podsols (with the exception of podsols of the extreme north) and true laterites show only minerals which are most resistant to weathering. In most cases they contain no minerals other than quartz and muscovite in their skeletons. In addition to them a number of other highly resistant minerals may be found, such as zircon, rutile, tourmaline and garnets. However, they are generally found in such small amounts that they are of no importance. In brown earths, orthoclase, plagioclases, biotite (though frequently in weathered golden brown scales and others might be found to some extent, in the deeper horizons, crystals of authigenic calcite, especially when developed from rocks and sediments high in lime. A greater variety of minerals, however, is seen in steppe soils. In desert soils and also in

other soils characterized by concentrated soil solutions, a large number of newly formed authigenic minerals may be found. In spite of the clear evidence of the close relationship between soil type and the variety of minerals to be found in them, as well as to the state of weathering of the different minerals, no detailed data have hitherto been available. Investigations in this respect will yield valuable contributions toward the general characterization of soil types.

In spite of the fact that the determination of the skeletal mineral grains in thin sections of soils is much simpler than in petrographical analysis, and that the methods for the determination of the minerals in the clay fraction are somewhat different, the pedologist should not forget that the knowledge of the minerals of unweathered rock, on which the soil is formed, is highly important for his work. Only comparative investigation of the minerals in the rock or mother substrata and their alteration in the corresponding soil, regardless of whether they have remained in place or have migrated to other horizons, can bring about a detailed understanding of the soil formation in each particular case.

3. THE DETERMINATION OF SOIL COLLOIDS AND CLAY MINERALS

Colloids can be recognized in thin sections only by less certain methods, such as observing their appearance and colors, and by some fabric reactions described previously. For investigations on their composition, therefore, the debris preparation is more suitable. The best methods are, in the first place, the determination of the colloids by their refractive indices, and, in the second place, by microchemical investigations which will be described in the following chapter.

Determination of mineral particles 20-1μ. Only the larger particles of the silt fraction may be determined satisfactorily in the thin sections. Smaller silt particles are, therefore, advantageously examined in debris preparation. For a number of soils a treatment with very dilute acid, alkali or with hydrogen peroxide will be necesary to remove colloid deposits from the grain surfaces. C. E. Marshall suggests a separation of the particles according to their size into three groups by repeated sedimentation and decantation (20μ-5μ, 5μ-2μ, 2μ-1μ). In the smaller fractions a new group of minerals, namely the so-called clay minerals, are observed besides those which

have been described in the previous paragraph. The clay minerals include aluminosilicates, ferric or ferrous silicates and also minerals with isomorphous replacement of Al by Fe. Their determination is somewhat difficult because they occur only in small particles. Their differentiation by X-ray examination will be confined more to the mineralogist because most of the spectra obtained are very similar and some results are not quite in accord. Optical criteria seem to be more sensitive as was particularly shown by C. E. Marshall (27-30).

The principal minerals, montmorillonite and halloysite, are best distinguished by their appearance and their behavior with crossed Nicols. Montmorillonite occurs mostly in the form of aggregates and shows distinct birefringence. Halloysite (metahalloysite) shows no birefringence and is usually observed in the form of fine plates, partly of aggregations of prismatic particles. Halloysite is easily transformed into metahalloysite when heated over 50°C. For the differentiation of the clay minerals the determination of the refractive indices is less suitable than for the minerals present in the soil skeleton. While fluctuation of the index in the case of halloysite seems to be produced in the main by loss of water, the variations in the case of montmorillonite, beidellite and nontronite (base exchange clay minerals) are also due to changes in composition. Marshall could show that cations found on clay are not only present on the surface but can occupy also definite positions in the layer lattice.

The refraction method can successfully be used in combination with other optical properties (mainly color, appearance, birefringence and extinction) for the recognition of different accessory minerals in the finer fractions, such as quartz, cristoballite, muscovite, bauxite, limonite, glauconite, chlorite, hydrated silicic acid, humus colloids, etc.

For the determination of refractive indices of small particles by the immersion method Marshall advised working in a dark room and the use of a microprojector to reduce eye strain. The preparation is pictured and enlarged then on a white screen. As immersion liquid Marshall suggests potassium mercuric iodide solution, which can be diluted with water to the required degree. Thus a set of mixtures with different refractive indices may be obtained.

Some optical characteristics of the most important clay minerals of the soil, as well as their composition and type

of structure, are given in table III (based on data contributed or collected by C. E. Marshall and partly also by C. W. Correns and his collaborators).

It is to be expected that the recent achievements of soil mineralogy will have an important influence upon the development of general pedology. Definite relationships between the occurrence of certain clay minerals and the different soil types, and the role of these minerals in the construction and dynamics of soils is not at present fully known, though a few studies on this subject have been made and further contributions are to be expected in the near future.

From the additional non-skeletal minerals listed in table IV, bauxite, hydrargillite and limonite are essential constituents, especially in laterites and lateritic soils. Glauconite occurs not only in marine deposits, but, as it has recently been shown, also in certain ground water soils. The occurrence of vivianite in peats, swamps and certain muck soils is well known. Pyrite in its blackish, powdery or earthy form is characteristic of many ground water soils high in humus in which, at the same time, gypsum (as its oxidation product) may be found. Soils containing considerable amounts of pyrite (which is injurious to higher plants) are easily recognized by the odor of sulfur dioxide when heated.

Determination of particles smaller than 1μ. Methods for the determination of the refractive indices of the smallest particles were especially used by A. B. Dick and C. E. Marshall with the application of dark ground illumination. A. B. Dick (cited by Marshall) found that particles of slightly smaller refractive indices than the immersion liquid show a purplish or bluish light; those of slightly greater, a yellowish or orange light. Marshall used a high power dark ground reflecting condenser which permits the determination of the refractive index to within 0.02. The slides of the preparations must be of the same thickness and air bubbles must be absent. A series of slides is prepared with drops of a set of potassium mercuric iodide solutions with different refractive indices prepared by mixing with definite quantities of water. The clay particles are suspended, and by careful comparison it is observed in which drop the bulk of particles is practically invisible. The method is less suitable for very heterogeneous clays or for particles with high birefringence. For particles down to a size of 200μ the use of a patchstop under an achromatic condenser is quite satisfactory.

TABLE I. *Characteristics of the most important uniaxial mineral grains*

Name	Chemical composition	Color and Pleochroism	Appearance	Refract. indices		Birefringence	Optical character	Solubility in acids
				ϵ	ω			
Quartz	SiO_2	Mostly colorless	Grain with vitreous lustre, surface smooth or with conchoidal fracture planes	1.54	1.55	Low 0.009	Positive	Soluble only in hydrofluoric acid
Calcite	$CaCO_3$	Colorless or milky	Rhombohedrons' grains, rod-shaped crystals, needles and powdery precipitations. Crystals dim or with vitreous lustre	Low 1.49	High 1.66	Very high 0.172	Negative	Soluble even in dilute acetic acid with effervescence
Dolomite	$MgCaC_2O_6$	Colorless white, grey or brownish	Grains and granular aggregates	Low 1.50	High 1.68	Very high 0.180	Negative	Slowly soluble in cold dilute HCl
Apatite	$Ca_4(CaF)(PO_4)_3$ $Ca_4(CaCl)(PO_4)_3$	Colorless white, green or bluish or brown	Grains or columns	1.63	1.63	Very low 0.003	Negative	Soluble in HCl and HNO_3
Tourmaline	Boron containing alumina silicate	Mostly black, brown, green. Pleochroism in dark green crystals	Small prisms or grains	1.62	1.64	High 0.020	Negative	Insoluble
Zircon	$ZrSiO_4$	Colorless, ochre or green. Pleochroism in dark crystals	Small prisms or grains	1.97	1.92	High 0.050	Positive	Insoluble

TABLE II. *Characteristics of the most important biaxial mineral grains*

Name	Chemical composition	Color and pleochroism	Appearance	Refract. indices			Birefringence	Optical character	Solubility in acids
				α	β	τ			
Muscovite	$KH_2Al_3Si_3O_{12}$	Colorless	Laminated plates and scales	1.56	1.59	1.60	High 0.039	Negative	Slowly soluble in HF
Biotite	Hydrated silicate of Al, Mg, Fe, and K	Brown, dark green; pleochroism sometimes in deep brown crystals	Laminated plates and scales	1.54	1.59	1.59	High 0.050	Negative	Soluble in conc. H_2SO_4; crystals rich in iron also in HCl
Chlorite	Water containing silicate of Al, Fe and Mg	Green, marked pleochroism	Laminated plates and scales	1.59	1.59	1.60	Low 0.011	Positive or Negative	Soluble in H_2SO_4 and hot HCl
Orthoclase	$KAlSi_3O_8$	Colorless	Prismatic crystal fragments with good cleavage	1:52	1.52	1.53	Low 0.007	Negative	Attacked only by HF
Albite	Na Al Si_3O_8	Colorless	Crystal fragments with good cleavage, all plagioclases generally show between x Nicols twinning lamellae	1.53	1.53	1.54	Low 0.008	Positive	Insoluble in HCl
Oligoclase				1.54	1.54	1.55	Low 0.008	Negative	Insoluble in HCl
Andesine				1.55	1.55	1.56	Low 0.008	Positive	Partly attacked by HCl

Labradorite				1.55	1.56	1.56	Low 0.008	Positive	Decomposable by HCl under formation of silica gel
Anorthite	$Ca\ Al_2Si_2O_8$			1.58	1.58	1.59	Moderate 0.013	Negative	Decomposed by HCl with precipitation of silica gel
Gypsum	$CaSO_4$	Colorless	Prisms, hemipyramids, lens crystals and grains with vitreous lustre	1.52	1.52	1.53	Low 0.010	Positive	Soluble in acids; difficultly soluble in water
Augite	$(Mg, Ca, Fe)(Al, Fe)_2SiO_6$	Black, blackish-green, blackish-brown, in some cases slightly pleochroitic	Prisms and grains	1.71	1.72	1.73	High 0.021 —0.026	Positive	Sometimes somewhat attacked by hot HCl, usually dissolved only in HF
Hornblende	Complex silicate of Fe, Mg, Ca, Al and Na	Dark green, brown, black, in thin sections sometimes almost colorless; marked pleochroism	Prisms and grains	1.64	1.64	1.66	High 0.013 —0.026	Negative	Practically not attacked
Epidote	$Ca_2(AlOH)(Al, Fe)_2(SiO_4)_3$ Al and Ca replaceable by Fe	Yellowish-green, sometimes brownish, in thick sections; weak pleochroism	Grains, small prisms with parallel striation	1.72	1.73	1.73	High 0.014 —0.050	Negative	Insoluble; after ignition, decomposable by HCl under formation of gels

TABLE III. *Optical characteristics of some clay minerals*

Name	Refractive index	Appearance	Birefringement	Extinction	Unsubstituted layers of the crystal lattices	Substitution
Halloysite	1.46–1.55	Fine plates, also aggregates of prismatic particles	Absent or very low	Isotropic	$Al_4(OH)_{12}$ $Si_4O_6(OH)_4$	.....
Metahalloysite	1.54–1.55	Fine plates	Absent	Isotropic	$Al_4O_4(OH)_8$ Si_4O_6	.....
Kaolinite	1.56–1.60	Mostly fine plates	Low 0.005–0.01	Oblique	$Al_4O_4(OH)_8$ Si_4O_6	.....
Pyrophyllite	1.55–1.60	Platy	High 0.04	Straight	Si_4O_6 $Al_4O_8(OH)_4$ Si_4O_6	.....
Montmorillonite	1.48–1.54	Aggregates showing rough surface	Moderate 0.01–0.02	Straight	Si_4O_6 $Al_4O_8(OH)_4$ Si_4O_6 $(H_2O)_x$	Mg for Al (Al for Si)
Beidellite	1.48–1.57	Fine plates or short blades	High 0.02–0.04	Straight	Si_4O_6 $Al_4O_8(OH)_4$ Si_4O_6 $(H_2O)_x$	Al for Si (Mg for Al) (Fe for Al)
Nontronite	1.56–1.65	Frequently blades and fibres (especially if Fe_2O_3 increased): Pleochroitic	High 0.02–0.04	Straight	Si_4O_6 $Al_4O_8(OH)_4$ Si_4O_6 $(H_2O)_x$	Al for Fe Mg for Fe

TABLE IV. *Characteristics of some other non-skeletal minerals in soils*

Name	Chemical composition	Color	Appearance and pleochroism	Refractive index	Birefringence	Extinction	Solubility
Limonite	$2Fe_2O_3 \cdot 3H_2O$	Yellowish to yellowish-brown	Amorphous earthy deposits translucent in thin section	Very high 2.0-2.3	.....	.....	.....
Bauxite	$Al_2O_3 \cdot nH_2O$	Colorless, more frequently yellowish to reddish-brown. (Stained with iron hydroxide)	Amorphous concretionary deposits	1.56-1.61	.....	.....	Attacked by alkalies
Hydrargillite (Gibbsite)	$Al_2O_3 \cdot 3H_2O$	Colorless	Whitish crusts, concretions, knobby or stalactitic formations; frequently lamellar	1.57-1.58	High 0.07	Oblique	Soluble in hot KOH; in hot HCl and in conc. H_2SO_4 slowly but completely soluble
Glauconite	$KMg(Fe,Al)_3Si_4O_{18} \cdot 3H_2O$	Olive green to yellow-green; sometimes pleochroitic	Grains or dense filling substances, partly transformed to limonite	1.61-1.65	Moderate 0.02	Straight	In hot HCl slowly soluble with precipitation of silica
Vivianite	$Fe_3P_2O_8 \cdot 8H_2O$	In fresh state colorless, blue, at least brownish (oxidized iron pleochroitic)	Round shaped aggregates or earthy accumulations	1.59-1.67	High 0.05	Oblique	Easily soluble in HCl and ammonia. Becomes black
Pyrite	FeS	Blackish	In soils blackish to blackish-brown, dull, earthy deposits	.....	Opaque	.....	Soluble with precipitation of free sulfur in conc. HNO_3

The measurement of birefringence of small particles even of ultra-microscopic size is performed on layers of particles oriented parallel to one another. The effect is additive and depends on the thickness of the layer. By evaporation of clay suspensions, flakes are obtained which sometimes even yield interference figures. The difficulty of measuring their thickness and incomplete orientation, however, makes them less suitable for actual determinations.

C. E. Marshall uses primarily particles in suspension in which the orientation is produced by an alternating electric current. The dilute clay suspensions are contained in parallel, sided cells furnished with platinum electrodes (27).

The soil colloids and their determination. By microscopic observation of soils a number of substances are recognized which show a continuous change in their state throughout the year. They are present in some periods to a great extent in a dissolved or peptized state, and may be obtained by evaporation of sufficient amounts of filtered soil solution. At other periods they are found freshly precipitated in the form of films or coatings around skeleton particles, or in the form of efflorescences on the surface of space walls, etc. Substances of colloidal nature are observed acting as protective colloids on other colloids; hydrophobous colloids are seen to be protected against precipitation by protective colloids. Because of their solubility they may migrate to other parts of the soil body which show definite traces of their movements in microscopic soil preparations.

Substances of this kind may be salts which crystallize in characteristic formations if the soil dries. They may be colloids which are liberated in the form of amorphous deposits by the evaporation of the soil solution in which they were dissolved or peptized. In addition to the inorganic colloids organic colloids are also observed, most commonly humic substances. The soluble or peptizable substances are important in agriculture because they alone are able to act as binding substances in the soil fabric. Their behavior in contact with the soil solution of the different soil types after their precipitation is one of the main factors determining the erodibility of a soil. Colloids may be present in either the dispersed or in the flocculated state. All the intermediate forms from strictly amorphous substances to aged colloids, showing more or less distinct crystalline structure, are observed.

The evidence for soluble or peptizable colloids is best seen

in the formation of grain films which are very thin and transparent membranes surrounding the mineral grains. In many cases these membranes can be made visible only by staining reactions. Hydrated silicic acid, iron hydroxide, ferrous compounds and humic substances are principally found as film-producing substances. Films of alumina or of aluminum compounds have not as yet been recognized. The films may be produced artificially by drying out certain concentrated soil solutions in quartz sand. Deposits of peptized colloids may be found also filling empty cracks, root channels, worm holes and other spaces, or in the form of surface crusts on space walls or on soil aggregates.

Most of the soil colloids vary greatly in their refractive indices, as was especially demonstrated by J. H. Hellmers and R. Köhler (31). Hence, among the optical properties the refraction is most useful in the identification of the soil colloids. In addition the microchemical reactions to be described in the following chapter are the most reliable. For fabric analyses staining reactions and other methods mentioned in one of the previous paragraphs will give valuable information.

The variation in the refractive indices of the inorganic colloids is primarily caused by differences in water content. The various kinds of colloids, however, differ so greatly in refraction that they still are well characterized by this property, especially in dried preparations. The influence of absorbed salts upon the refractive indices is of minor importance.

Silica gel of 12 per cent water shows a refractive index of about 1.43 to 1.44, more or less corresponding to the refractive index of opal. With aging and crystallization the refractive index in nature becomes higher, due to further loss of water, up to the formation of chalcedony and later quartz (about 1.55). The refractive index of pure air-dried aluminum hydroxide gel is about 1.57-1.58. Dried mixtures or compounds of colloidal silica and alumina may have any refractive index between those of the pure colloids, varying with the ratio of the components. The refractive index of iron hydroxide is very high, being usually greater than 2.0. Dry humic substances range usually between 1.59-1.63. Generally both iron hydroxide and humic substances occur in association with silica and alumina. Their presence is not only marked by their strong color but also by their influence on the refractive index. Colloid gels with increasing brown coloration generally also increase in refraction. It is, therefore, possible to a certain

extent to draw conclusions from the refractive index of colloids as to their approximate composition. The prevalence of iron hydroxide on the one hand and of silica on the other is also visible to some extent in staining preparations with malachite green. Brown-colored colloidal gels with high silica content show an intense blue-green color with malachite green; those high in iron hydroxide either a yellowish-green color or, in marked prevalence of electropositive colloids, no coloration at all. Colloids high in silica show microscopically a particularly wax-like lustre and appearance. A comparative diagram of the refractive indices of different soil colloids is given in fig. 55. The data, as far as the colloids are concerned, are based upon the investigations of J. H. Hellmers and R. Köhler (31).

CHAPTER IX

Microchemical Methods

In soil microscopy microchemical tests play an important role, especially for the identification of the non-skeletal parts of the soil including the different efflorescences and depositions in the soil spaces. Quantitative microchemical analysis has hitherto been used only for the determination of the silica-sequioxide ratio of isolated colloid fragments. It is very likely that it will become a useful application for a number of other investigations in the future.

The performance of qualitative microchemical investigations is relatively simple, and is further aided by the fact that only a limited group of elements and compounds have to be considered. Prior to making the tests, the color and appearance should be noted since these are very helpful in deciding which methods and reactions to apply. White-colored substrates exclude the presence of ferric compounds and humic substances. Specimens turning red after ignition indicate ferric compounds. Brown-colored material, which may be removed by ignition or charred by burning, is due to the presence of organic compounds. Black-colored deposits which are not changed by ignition, are mostly manganese oxides. A waxy appearance means, in the majority of cases, the presence of high amounts of peptized silica gel. Hemipyramids and lens-shaped crystals are generally gypsum; rhombohedrons, rounded rods and fine needles are usually calcite, etc.

1. GENERAL TECHNIQUE

Equipment. For chemical investigation an old or inexpensive microscope should be used. Objectives with working distances down to 16 mm., or in some cases to 4 mm., will usually be sufficient. The front lenses of the objective should be protected against acids and other chemicals by a round cover slip cemented with Canada balsam to the lower opening of a piece of glass tubing (about 25 mm. long) of a diameter slightly wider than the diameter of the objective. The objective is enclosed in a piece of rubber tubing and the glass cylinder put over

the rubber ring so that the cover slip is kept close to the front lens of the objective. For brief use a cover slip may be fixed to the front lens by a drop of immersion oil.

The additional equipment consists of slides, cover slips, glass rods, micropipettes, platinum loops, microspatulae, a microplatinum spoon or microplatinum dish, nickel forceps or forceps with platinum ends, a microburner, filter paper, and a set of reagents in small phials or pipette (dropping) bottles (for liquid reagents).

The most convenient size of slides for all microscopic soil investigations (except those for microbiological purposes) is 48 x 28 mm. A thickness of about 0.7 mm. is preferable for microchemical work. This thickness allows rapid heating of the liquid drops and also rapid cooling accomplished by placing the slide on a large glass plate. The cooling of thick slides may take place too slowly and may result in the rapid evaporation of the solvents and in a failure of the reaction. It is advisable to clean the slides with alcohol and prepared chalk before use. For investigations with hydrofluoric acid the slide is first coated with collodion. Instead of glass slides, uncoated plates of mica may also be used.

Filtration. For filtration various types of microapparatus have been designed. A simple and practical filtration is performed with a small glass tube or pipette with an evenly ground lower end. A small piece of thick filter paper is put close to the drop to be filtered and the lower end of the pipette placed on top of the filter paper (Hemmes method). The filtration is performed by sucking at the upper end of the pipette by means of a rubber tubing and mouth piece (as pictured in fig. 56). A similar method consists of using a thin glass tube with a plug of cotton, filter paper or asbestos at its lower end, which is dipped into the drop to be filtered. The filtrate accumulates inside the glass tube and can be removed after the plug is taken out by a pair of microforceps.

Testing on slides. Most of the reactions are carried out directly on slides. The substance to be tested is dissolved in a drop of solvent; then a drop of a reagent is added to it or placed close to the test drop. In the latter case both drops are united by forming a channel of liquid between them by means of a fine glass rod or a platinum wire. Sometimes a small piece of solid reagent is introduced directly into the test drop. During the carrying out of the reaction the preparation generally is kept uncovered.

Reagents necessary. The following list includes the most necessary reagents for microchemical investigations of soils.

Sodium chloride	Ferric chloride
Sodium nitrate	Uranyl acetate
Sodium carbonate	Iodine potassium iodide sol.
Sodium phosphate (Na_2HPO_4)	Phloroglucinol sol.
Sodium azide	Chlor-zinc iodide sol.
Seignette salt	Campeachy-wood
Potassium chlorate	Malachite green
Potassium copper lead nitrite	Gelatine
Potassium ferrocyanide	Acetyl bromide
Potassium ferricyanide	Hydrochloric acid 1:10
Silver nitrate	Hydrochloric acid 1:1
Cesium nitrate	Hydrochloric acid conc.
Calcium chloride	Nitric acid 3 per cent
Calcium acetate	Nitric acid 1:1
Barium chloride	Sulfuric acid 1:1
Aluminum chloride	Sulfuric acid 3:1
Bismuth oxynitrate	Sulfuric acid conc.
Ferrous sulfate	Hydrofluoric acid

2. THE MOST IMPORTANT QUALITATIVE MICROCHEMICAL REACTIONS FOR THE INVESTIGATION OF SOIL

SODIUM

Uranyl acetate. The reagent is prepared by dissolving 4 g. of uranyl acetate in 100 cc. water and by adding 4 drops of glacial acetic acid. The liquid is slightly heated. The cooled reagent must be free from undissolved crystals.

The test drop is evaporated on a slide and, after cooling, a drop of the reagent added. In this case no heating is necessary. If the reagent is applied to a liquid test drop, slight but cautious heating may be used. Immediately, or after a short time, small colorless to slightly yellow tetrahedra of sodium uranyl acetate will appear if sodium is present (fig. 57). In the presence of magnesium the crystals are distorted. The reaction is very sensitive and is considered even more sensitive than the flame reaction. The presence of potassium, however, prevents the formation of sodium uranyl acetate. In this case the following reaction may be used.

Bismuth oxynitrate. To the test drop some crystals of bismuth oxynitrate and a drop of sulfuric acid 1:1 is added and the slide heated over a microburner. In the presence of sodium,

colorless small and short rod crystals are formed (fig. 58). They are nearly always single and appear as druses only in high concentrations.

Flame reaction. The flame reaction is particularly useful for the differentiation of sodium and calcium efflorescences. The efflorescences directly, or after solution in hydrochloric acid, are placed on a platinum loop and brought into a microflame. Sodium salts produce an intense yellow coloration of the flame.

POTASSIUM

Triple nitrite $Na_2CuPb(NO_2)_6$. The reagent is prepared by dissolving 20 g. sodium nitrite, 9.1 g. copper acetate, 16.2 g. lead acetate and 2 cc. acetic acid in 150 cc. water. The reagent must be renewed frequently because of loss of nitrous acid. A grain of the substance to be tested, placed into a drop of the reagent, will yield without heating, blackish-violet cubical crystals which are almost opaque (fig. 59). The reaction also is effective in mixtures and in the presence of sodium.

Bismuth oxynitrate. The reaction is carried out in the same way as in the case of sodium. The presence of potassium is indicated by the formation of transparent hexagonal plates of potassium bismuth sulfate (fig. 60).

CALCIUM

Sulfuric acid 1:1. The reagent and the test substance, dissolved in a drop of warm dilute hydrochloric acid, are united in one drop. Crystals and efflorescenses of calcium carbonate are introduced directly into a drop of the reagent. The reaction is best performed with dilute solutions, which are gradually concentrated by gentle heating. Calcium is precipitated in the form of needles and twin crystals of gypsum. Crystals slowly growing from dilute solutions may be observed in the form of swallow tails as well as in the form of the characteristic x crystals (fig. 61).

Seignette salt. This reagent is especially useful for the investigation of gypsum. The specimen (not too small a portion) is introduced into a drop of acetic acid and a somewhat larger portion of seignette salt (sodium potassium tartrate) in solid form added. The crystals of calcium tartrate (orthorhombic prisms) generally appear slowly (fig. 62). The reaction may be accelerated by gentle heating and the addition of some alcohol.

Flame reaction. Efflorescences of calcium carbonate in sufficient quantity adhering to a platinum loop (either directly or reprecipitated from solution in hydrochloric acid) gives an intense red coloration in the microflame.

MAGNESIUM

Sodium phosphate. To the test drop a small grain of ammonium chloride and a drop of ammonia is added. After gentle heating, a small grain of sodium phosphate (Na_2HPO_4) is introduced. The crystals of ammonium magnesium phosphate produced appear in the form of dendritic stars, and later in the form of orthorhombic crystals resembling envelopes or lids of coffins.

IRON IN FERRIC FORM

Potassium ferrocyanide. If dissolved in dilute hydrochloric acid some solid reagent is added. Undissolved specimens are treated with a drop of dissolved potassium ferrocyanide followed by a drop of dilute hydrochloric acid. The presence of iron is indicated by the formation of dark blue precipitations of Prussian blue. The reaction is superior to all other methods.

IRON IN FERROUS FORM

Potassium ferricyanide. The reaction is performed in the same way as the previous test. The best concentration of the potassium ferricyanide solution is 2 per cent, which is applied in combination with 5 per cent hydrochloric acid. Ferrous compounds give blue precipitates of Turnbull's blue. Ignited ferrous compounds act as ferric compounds with potassium ferrocyanide.

ALUMINUM

Cesium bisulfate. The reagent is prepared by evaporating a solution of cesium chloride in excess of concentrated sulfuric acid in a small porcelain dish. The sulfuric acid is so far removed that after cooling a soft crystalline mass is obtained. The bisulfate is dissolved by adding a few drops of water to give, with gentle heating, a highly concentrated solution (34).

The substance to be tested is dissolved in hydrochloric acid. The test drop is evaporated almost to dryness and a minute drop of the reagent added with a platinum wire. Excess of hydrochloric acid should be avoided. The cesium alum crystals will at first appear, without heating, in the form of large dendri-

tic crystals. After addition of some water and gentle heating glassy clear octahedrons will be formed (fig. 63).

Alizarin spot test. The test drop is placed on a filter paper instead of a slide. The best filter paper for this purpose is the so-called spot paper, No. 601, of Schleicher and Schüll, Düren and New York. A drop of alizarin is placed on the spot and the filter paper held in ammonia vapor (over the opening of an ammonia bottle). A drop of ammonia may be added as well. In the presence of aluminum a reddish-violet stain, which turns to red, is produced. This test is one of the spot reactions originated by F. Feigl in Vienna (33).

MANGANESE

Melting test. Manganese compounds fused with sodium carbonate and sodium nitrate in a platinum loop give a green coloration produced by the formation of sodium manganate. Excess of manganese results in a black coloration.

Benzidine acetate (spot test). The test drop is placed on a spot paper; then one drop of ammonia, one drop of hydrogen peroxide and a drop of benzidine acetate is added. The presence of manganese is indicated by a blue coloration.

CHLORIDE

Silver nitrate. The substance is dissolved in water and a drop of silver nitrate is added to the test drop. The precipitate is treated with a drop of ammonia. After the evaporation of the ammonia (without heating), small crystals (10-20μ) of silver chloride, visible on examination with a 4 mm. objective, are formed (fig. 64).

SULFATE

Calcium acetate. When this reagent is added to the test drop, calcium sulfate crystals are formed in the presence of sulfates (fig. 61). If no reaction takes place a drop of ammonium acetate may be added to the mixture.

Calcium chloride. The characteristic calcium sulfate crystals also may be obtained by acidifying the test drop by hydrochloric acid and by introducing a grain of calcium chloride into its center. The gypsum druses will appear at the margin of the test drop.

Barium chloride. The test solution is mixed in a micro-test tube with dilute barium chloride solution, which results in a white precipitate of barium sulfate.

Gypsum test. Small granular precipitates of gypsum are dissolved in hot water. The test drop, slowly concentrated by evaporation, will show recrystallization of gypsum at the margin. The crystals can be characterized with the polarizing microscope.

CARBONATE

Hydrochloric acid. The substance is embedded in a drop of slightly warmed gelatine gel. After cooling and setting of the gel, a drop of dilute hydrochloric acid 1:10 is placed on the slide touching the gelatine mass. The acid penetrates slowly into the gel, and as soon as it reaches the substances tiny bubbles of carbon dioxide are set free. The reaction is performed under the microscope. The gelatin is dissolved by slight heating in water.

Campeachy-wood aluminum chloride reagent. (See p. 81.)

SULFIDE

Sodium azide and iodine (Feigl-reaction). A small specimen of soil pyrite and a crystal of sodium azide are placed on a slide or small watch glass and a drop of iodine solution added. The sulfide is indicated by the evolution of little gas bubbles of nitrogen. The test is based upon the catalytic acceleration of the reaction between sodium azide and iodine.

Odor test. The odor of hydrogen sulfide evolved by dissolving pyrite in acids can be recognized even with small amounts of the mineral.

SILICATE

Malachite green. The substance to be tested is powdered and slightly ignited in a platinum spoon. After cooling it is moistened several times with hydrochloric acid and the acid evaporated. Finally, the substance is treated with several drops of dilute hydrochloric acid and the soluble parts removed by filtering and washing. The white residue of silicic acid is stained with malachite green.

Hydrofluoric acid. Silica is volatilized in the form of silicon fluoride when cautiously heated in a microplatinum spoon with hydrofluoric acid which is kept in a reagent bottle of ebonite.

Hydrofluoric acid and sodium chloride. More or less pure silica can be recognized by placing the substance on a slide with a coating of collodion, and by adding a drop of slightly dilute hydrofluoric acid and some sodium chloride. After some time, hexagonal crystals of sodium fluosilicate are produced in

the form of characteristic, seemingly reddish-colored plates, stars, rosettes, and combinations of pyramids and prisms. Alkali salts which may disturb the reaction are removed by previous washing.

3. SOME SPECIAL MICROCHEMICAL INVESTIGATIONS OF SOIL CONSTITUENTS.

WHITE EFFLORESCENCES OR DEPOSITIONS

The substances are microtechnically isolated from the soil, and, if not uniform, divided into different groups by micromechanical analysis (see p. 43). The latter is performed only if the separation is possible or practicable. The substance then is investigated microscopically to determine whether it consists of amorphous or crystalline particles, whether the particles are isotropic or anisotropic, or if crystal forms can be observed. The results may shorten the chemical investigation considerably or cause the worker to confine himself entirely to their determination by means of optical properties. If the crystals are very small, solution in a drop of water and recrystallization of the substance by slow evaporation of the test drop may be tried.

For the microchemical test a small quantity of the particles is spread on a slide, covered with warm gelatin gel and, after cooling and setting of the gel, treated for carbonates with hydrochloric acid. A specimen of the substance is then treated with water and the undissolved parts observed under the microscope. Several drops of the solution are evaporated on a microplatinum dish, slightly ignited and, after cooling, redissolved in water. The residue is tested for silica (malachite green). If no silicic acid is present, different drops of the solution are taken for the determination of sodium, potassium, calcium, magnesium, sulfate, chloride and carbonate.

The residue insoluble in water is taken up with hydrochloric acid and different drops tested for calcium, magnesium, alumina, carbonate, sulfate and silicate. Silicic acid, if present, is removed before other tests are performed.

RED-BROWN OR OCHRE-COLORED INORGANIC COLLOID-LIKE SUBSTANCES

Homogeneous fragments of the substances generally found as binding and filling matter between the mineral grains are collected, crushed on a microplatinum dish and ignited for one minute. The substance is extracted with warm 3 per cent nitric

acid (HNO_3 1.2 ten times diluted). The acid dissolves alumina which is determined as cesium alum; iron oxide and silica remain undissolved (see 34, p. 229). Iron is extracted then with concentrated hydrochloric acid and the silica residue determined with malachite green or volatilized by hydrofluoric acid.

MANGANESE IN FERRUGINOUS SUBSTANCES

The melting test for manganese is more effective if iron is removed. The substance is dissolved in nitric acid and boiled with potassium chlorate until the dark brown precipitation of manganese peroxide is formed. The precipitate is washed with nitric acid and a very small portion tested with sodium carbonate and sodium nitrate in a platinum loop.

4. SIMPLE REACTIONS FOR SOME ORGANIC COMPOUNDS IN THE SOIL

Lignin. The preparation is treated with an alcoholic solution of phloroglucinol followed by concentrated hydrochloric acid. Lignin particles will then appear a violet red or cherry red color. Preparations must be kept in the dark; otherwise, they lose their color very soon. The color in old lignin preparations changes to a yellowish tint.

Lignin is optically isotropic and is destroyed by acetyl bromide, while certain humic substances are almost unaffected. It is insoluble, however, in cold 75 per cent sulfuric acid, which dissolves cellulose and other plant polysaccharides.

Cellulose. The preparation is treated with a dilute solution of iodine in potassium iodide (0.3J, 1.5JK, 100 water). After some time diluted sulfuric acid (3 + 1) is added, resulting in a blue coloration of all cellulosic parts. Usually, one drop of water is placed on the separation followed by two drops of concentrated sulfuric acid. The reaction should be performed in such a way that the swelling of the cellulosic parts is avoided as much as possible. Excess of iodine solution results in the formation of disturbing iodine precipitates, and also causes the preparation to be dissolved too rapidly. The iodine-sulfuric acid reaction is very satisfactory with pure cellulose. Since cellulose occurs only rarely in the pure state, the clearness of the reaction is much influenced by the amount and kind of associated substances. Preparations kept in potassium hydroxide for some time usually yield considerably better results.

Similar to the iodine-sulfuric acid test is the effect of the chlor-zinc iodide reaction, which gives a more or less violet color

with cellulose. This reagent, consisting of 25 parts zinc chloride, 8 parts potassium iodide, 1.5 parts iodine and 8 parts water, must be protected from light by storage in a brown glass bottle.

Cellulose is also dissolved in 72 per cent cold sulfuric acid when associated with other substances. It is soluble in cuprammonium, if present in the pure state. Lignin or encrusting polyuronides must be removed before treatment. Cellulose is optically anisotropic.

Chitin. Fragments of chitin, in almost all cases representing residues of the outer integuments of mites, insects and other soil animals, are only slowly decomposed in all soil types. The original animal structure is therefore usually well preserved and may often be identified directly.

Chitin is stained brownish by iodine solutions. After addition of hydrochloric acid, the color changes to a reddish tint or sometimes to a more or less violet color which can be intensified by the addition of sodium chloride solution.

Chitin shows no protein reactions and is optically isotropic. It is insoluble in water but soluble in dilute acids. In concentrated hydrochloric acid or sulfuric acid it is soluble and gives a brown-colored solution.

The cell membranes of fungi, including the fungi imperfecti, consist generally of chitin. The isotropic fungus filaments are thus easily distinguished from the anisotropic root filaments with the polarizing microscope.

Tannins. Treatment of tannins with certain iron compounds results in the production of blue, bluish-black or green colorations. The best reagents are ferrous sulfate in concentrated solution and ferric chloride in dilute solution with 10 parts water (the reagent is always kept in concentrated state and diluted before use).

This group comprises a number of non-nitrogenous substances of different chemical nature, most of which have the property of rendering organic substances (proteins) resistant to decomposition. Because of this property tannins play a particular role in certain humus types (especially forest soils). They are mostly water and alcohol soluble.

5. MICRO-pH DETERMINATION

Micromethods of pH determination allow a direct investigation of the natural soil solution. The pH of the soil solution is not only changed in the different stages of wetting and drying of the soil, but great changes may also be noticed in different

microscopic locations of the soil according to the influence of salt accumulations, chemical processes and the activity of microorganisms.

Micro-indicator foils. For the micro-pH determination the author cuts the indicator foils of Wulff (for sale by F. Lautenschläger, Munich, Germany) with a razor blade or fine scissors to small strips of about 0.5-0.7 mm. The Wulff indicator foils, used for macroscopic pH tests, are cellulose membrances containing absorbed indicators. The microfoils produced by cutting are introduced into the test drop and the change of color is observed. It is advisable to prepare a microcolorimetric scale from the macroscale generally sold by Lautenschläger with the indicator foils. The translucent foils of the scale are fixed in the form of small strips on a slide. The corresponding pH figures are marked with a diamond. The scale is covered with a cover slip of the size of the slide, and the margin of the slide closed with black tape. The microcolorimetric scale is placed on the microscope stage underneath the slide with the test drop containing the indicator foil. By alternate focusing on the indicator foil and on the different foils of the scale underneath, the corresponding indicator color and pH value is found. For the test drop it is better to use a cover slip instead of a slide. Dry soil fragments are tested by suspending in a drop of boiled water about twice the volume of the soil specimen (4).

In spite of the fact that this method allows but an estimate, rather than a quantitative determination of the pH, it is quite satisfactory and helpful for microbiological purposes. More accurate figures, if desired, may be obtained by using drops of buffer solutions instead of the microcolorimetric scale. A set of different buffer solutions is kept in dropping bottles. To apply this test several drops of different pH close to the conjectured pH of the test drop are placed near to the latter on the same slide. A micro-indicator foil is introduced into each drop and the change of color observed. The conformity of the color of the foils in the test drop with one of the buffer solution drops of known pH, allows the recognition of the pH of the test drop.

Micro-quinhydrone electrode. Micro-pH determinations of soils have been performed also by F. Sekera (Hochschule für Bodenkultur, Vienna) by using a micro-quinhydrone electrode (35). The determination can be carried out directly in the soil after sprinkling the parts to be tested with fine quinhydrone powder. The investigations have been performed primarily for testing the pH in close proximity to the root hairs of higher plants (see p. 207).

Part III
SOIL FABRIC

CHAPTER I

Introduction

1. PRINCIPLE AND GOAL OF FABRIC ANALYSIS

By "soil fabric" we mean the arrangement of the constituents of a soil in relation to each other. Some soil horizons may show no changes in arrangement when examined in different directions with the microscope, while some others may exhibit very marked changes. The differences in arrangement are caused by past differential movements of all or some constituents. From the study of the arrangement we can draw conclusions concerning the kind and the direction of the movements.

The totality of movements of components, which occur in a given soil, is called the dynamics of the soil. Since the soil can change its dynamics remarkably during the course of the year and during the different stages of its development, the modern pedologist does not classify soils according to their properties, but according to their dynamics. The term, "soil type," is an expression for the totality of its dynamics, that is, of all the component movements possible in a given soil. "Soil type," as an expression of its dynamics, refers not only to the regional and local climates, but also to the position, surface relief, plant growth, water conditions, and internal construction of the soil, mainly the grain sizes, density, permeability and specific type of the fabric, as well as the chemical nature of the original constituents. The final goal of microscopic fabric analysis is the recognition of the dynamics of a given soil, the creation of refined research methods by which it is possible to disentangle the complexity of microscopic events, in order to recognize the detailed movements of the different components represented in chemical and morphological transformations or in displacements. The detailed knowledge of the different processes involved will contribute to our understanding of the genesis of soils as well as to their classification. In coherent soils almost every microscopic happening, as far as it was not succeeded and covered by another happening, has left its picture in the fabric. In the microscopic fabric we are able to read the history of a soil as we may a book. We need only to learn to interpret that which we find in it.

However, not only can conclusions as to the past processes of the soil be drawn from the fabric, but also the details of its behavior in the future, primarily in the sense of its agricultural efficiency, can be predicted. It will require some time and detailed studies to pass only theoretically through the domain of fabric analysis. It has been shown, however, on several occasions, that a successful application to practical soil science is possible at the very beginning. With almost every kind of practical problem we can receive new and valuable data by supplementary microscopic investigations. In the earlier stages of medicine the diseases of the interior of the body were diagnosed only by outer symptoms. Only in the later medical science were the organs and tissues opened for independent study with regard to their formation and their function in the living body. In like manner we begin now to open the natural soil as an organism-like body, and to study the details of its formation and the function of its different parts in relation to the whole.

2. MEMBERS OF SOIL FABRIC

The components which constitute a fabric may be of simple or of compound construction. Both represent fabric units. We distinguish fabric units of lower and of higher order. A building is constructed of numerous single stones which represent some of the fabric units of the building. Every single stone, however, also shows a construction of its own. Suppose the building were constructed by brick-shaped artificial stones consisting of round gravel, angular grains of sand, and a dense binding substance of lime filling the spaces between the sand particles and the gravel. Gravel, sand grains and cementing substance represent the fabric units in the single building stone. The way they are arranged would represent a counterpart of what we call the elementary fabric in the soil. A fabric unit, similar to the building stones, is found in the aggregates in the soil. Besides the building stones, units of higher order are distinguishable. If the building were a dome, we would distinguish different parts which are arranged together to make up the whole. Such units of higher order would be the arched buttresses and the arch-masonry. By analogy we are able to state fabric relationships in the soil which are based on units of higher order. The different grades of fabric relationships in the soil—the elementary fabric, the fabric of aggregates and wall complexes, the fabric of cleavage blocks or of other fabric

units of higher order—are called members of the soil fabric. The different fabric members are contained in each other; they are present at the same time and fill the same space.

3. NOMENCLATURE

The term, "soil fabric," is a counterpart of the term, "rock fabric," created by B. Sander for the arrangement of the mineral grains in rocks determined by their optical orientation or their shape orientation (36, 37). Although in soil fabrics other relationships and other materials are more prominent, the denotation and sense of the idea are the same in both fields. Also the science of soil fabric, with its observations and results will be able to contribute to a science of general fabric to be created in the future.

The author, therefore, found much justification for using the term "fabric" for the arrangement of the constituents of the soil, and their role in relation to each other, instead of "structure" or "texture" (the latter in the European meaning). Another reason for this decision was the fact that the terms "structure" and "texture" in soil science in the different countries have different meanings.

In the old petography, and in the old soil science in Europe, the one comprehensive term "structure" was used, which referred to all the ideas later developed in petrography and expressed by the terms "Gefüge," "Textur" and "Absonderung."

In the new German petrographic literature the terms have come to mean for the most parts the following: By "structure," the form, relative size and reciprocal boundary lines of the components (minerals) are understood; by "texture," their arrangement and distribution in the space; and by the term "Absonderung," complexes formed by the natural cleavages, as in the formation of columns and plates.

In pedology, as in German petrography, it will become advantageous to use several detailed expressions for the different conceptions enumerated above instead of using only the term "structure" for all. A beginning in this respect was made by the adoption of the term "texture" in soil science in Europe and in America. Unfortunately, the same expression was used in the opposite sense; in America it meant the grain sizes, and in Germany it had several meanings, the chief of which was the form and relative size of the soil spaces (the German term for grain sizes is "Körnung").

Of all the terms, "texture," applied in the sense of German petrography, comes closest to the author's conception of soil fabric. It was avoided, however, because "texture" in the United States and other countries has been in general use for many years in the sense of grain sizes. The term, "structure," in the agricultural sense, means the general appearance of the soil, as consisting of crumbled or flocculated aggregation complexes or, in the opposite case, as lacking in such complexes. The microscopic investigation shows that the term, "structure," used in this sense, describes only the macroscopic appearance of different fabric relationships which show in microscopic dimensions pictures other than the conjectured "crumb" or "single grain" arrangements. By the introduction of the new expression, "soil fabric," the meaning of the term, "soil structure," used in agricultural soil science over almost all the world, will not be influenced. The author also will use "structure" occasionally in microscopic investigations where he does not mean the arrangement of components and their relation to other constituents, but the mere appearance of a component in regard to its outlines, the designs observable in its interior, etc. Thus, the old terminology remains untouched, and no old term is used in a sense contrary to its application in any country at present.

CHAPTER II

Elementary Fabric

1. GENERAL

By elementary fabric (German—Elementargefüge, French—assemblage élémentaire) is meant the arrangement of the constituents of lowest order in the soil and their relation to each other.

These constituents represent more or less independent units, and, in most cases, more or less homogeneous bodies. Not all soil constituents of these kinds can be considered as fabric units in the sense of elementary fabric. We have to distinguish between the principal building elements and accessory constituents. Fabric units may be grains or fragments of rock minerals, particles of raw humus (which may also serve as skeleton), films, coatings, grain deposits, intergranular braces and space deposits of salts, colloids and suspended substances. The accessory constituents may be of particular importance for the character of the soil. They are, however, of minor importance in the construction of the soil, and the regular arrangement of its building elements, which represent genetically, in most cases, the primary constituents. Accessory elements, in this sense, would be locally limited crystal formations and accumulations of substances, space-fillings of fungus mycelium or organism remnants, cysts of protozoa, etc.

According to the role of the different fabric units of lowest order, we are able to distinguish two different groups. One forms the *skeleton* of the fabric, which consists mainly of the residues of rock minerals and organisms not decomposable or which are only slowly decomposing. The units of the other group are much more easily moved, changed in composition and shape, and redeposited. The latter are generally identical with the finely dispersed and highly active, newly-formed compounds in the soil. They are pedogenetically the most important ingredients of the soil, and represent the real carriers of the typical properties of the soil. In order to characterize their nature in comparison to the skeletal units we call them, as a whole, the *fabric plasma.*

Factors influencing the formation of fabric types. The regular formation of definite elementary fabric types is caused, in the first place, by the manifold influence of flocculation and peptization on the morphology and mobility of the fabric plasma. Flocculation and peptization may act upon the different substances of the fabric plasma in different ways, that is, the substances react differently to treatment by one and the same natural reagent. The kind and strength of electric charge, and its influence on the different soil colloids, the ability of alkalies and acids to dissolve components of the plasma, the protective effect of hydrophilic colloids, and finally the action of the eluvial and illuvial processes in general, bring about remarkable divergences in the fabric of soil types. The repeated drying out of the soil, especially if accompanied by irreversible processes, effects to a great extent the microscopic fabric. Finally, the morphological properties of the components, as sizes and shapes of particles and the quantitative relationship between the constituents, are important in determining the type of arrangement.

Stability of elementary fabric. Like the formation of horizons, the formation of elementary fabric is also an expression of the soil type produced by the continuous influence of certain soil forming processes over prolonged periods of time. As long as these processes are not changed the elementary fabric will show no changes, except those which are characteristic for the particular soil type in the different stages of its development.

The elementary fabric is not obliterated by mechanical destruction of the soil produced by breaking, crushing or tilling. It is preserved in the smallest aggregations or fractions; in many cases it may be recognized even on single soil grains and in the way the plasma residues are arranged on its surface. By knowledge of the elementary fabric we may draw conclusions as to a number of other properties of the soil correlated with it and with the soil type.

As it is possible to influence a given dynamic of a soil artificially by treatment with chemical substances, or by changing its water and air conditions, it will be possible also to influence its elementary fabric.

Advantages to expect from fabric analysis. The fabric investigations concern not only the mere arrangement of the components, but also the study of the components themselves, their morphology and chemical nature. The variety shown by the elementary fabric in general is so great that its knowledge will

contribute not only to the genesis and classification of soils, but also to the recognition of soils present only in smallest quantities in regard to the respective soil type or subtype and horizon. It will be possible to conclude, even from the minute soil particles adhering on the roots of plants after years in herbariums, as to the climate and general nutrient conditions of the location where they had been growing.

2. EXPERIMENTS IMITATING THE FORMATION OF SOME FABRIC TYPES

Experiments imitating chlamydomorphic fabric. About 7 grams of pure glass sand (quartz sand) of an average grain size of 0.5 mm. are mixed with 0.2 gm. iron hydroxide, and 2.5 cc. hydrochloric acid (1:10) added to the mixture. The suspension is shaken until the iron hydroxide is entirely dissolved. The suspension is then poured into a small glass dish and left to dry out at room temperature. The microscopic picture of the dried sand shows that every glass or quartz grain is covered by a uniform lemon yellow coating of $FeCl_3 + 6\ H_2O$ (Ferrum sesquichloratum. On slight heating the color is changed to brown, caused by loss of water ($FeCl_3 + 3\ H_2O$). On ignition the coatings turned into dark gray; on cooling, however, they are changed into an intense bright red (Fe_2O_3). The grains are combined with each other at the junction points and form partly coherent but very friable complexes. In the angles of the intergranular spaces the coatings are thicker and have deeper color. In the center of the junctions a round bare spot can be observed. Instead of intergranular braces, we find only a ring-shaped thickening of the coatings, a round accumulation of iron oxide of a shape resembling the margin of a crater. Accumulation of iron oxide can be seen also in the cracks and dents of the grain surface. The arrangement thus produced represents a construction similar to that which will be discussed later as chlamydomorphic fabric in soils.

A similar result can be obtained by application of distilled water in place of the hydrochloric acid above, particularly when it shows a more acid reaction or when some carbon dioxide is introduced into it. After drying, the sand grains are surrounded by iron coatings which readily become visible after ignition. Besides the coatings some granular deposits of undissolved iron oxide particles may be generally observed on the surface of the grains.

Experiments imitating agglomeratic fabric. Seventy parts of

pure quartz sand are mixed with two parts of iron hydroxide and suspended with twenty-five parts of water. Then one part of calcium oxide is added, the suspension is shaken and poured into a small dish where it is dried by slight heating. The microscopic investigation shows the absence of coating formations. Instead deposits of flocculated iron hydroxide and some deposits of calcium hydroxide may be found in the intergranular spaces. The cracks and dents of the grain surfaces are free from iron accumulations. The sand does not form complexes, and the iron hydroxide does not act as a binding substance in this case. The arrangement corresponds to an arrangement in soils which we designate as agglomeratic fabric.

A similar effect may be produced by using tap water without addition of calcium oxide.

Experiment imitating chernozem fabric. John B. Bartlett, of Ames,* mixed 25 g. pure quartz sand with 70 mg. fine particles of lignin and placed the mixture in a small petri dish of a diameter of 1.5 inches. To the dry mass 6 cc. of 5 per cent NaOH were added. A part of the lignin went into solution at once, producing a deep brown coloration on the bottom of the petri dish. The next day the deep brown coloration had moved to the evaporating surface of the sand, while the deeper layers showed a lighter degree of brown. The material was left to dry out at room temperature.

The microscopic investigation showed that the undissolved grains of lignin were deposited in the angles of the intergranular spaces and cemented to the quartz grains by dissolved lignin, part of which was seen in the form of slightly brownish films on the surface of the quartz grain.

A very constructive picture of the fabric relationships could be obtained by the thin sections, which were made somewhat thicker for this purpose (about 0.08 mm.). The quartz grains were ground until only their caps on both sides were taken off. Almost all grain-like lignin was deposited in the angles of the intergranular spaces. The film nature of the dissolved lignin was clearly shown. In the center of each grain, where the caps had been ground off, appeared a white spot which was round and regular in the case in which the contours of the caps on both sides of the section were congruent.

This arrangement corresponds to the intertextic fabric in chernozems and other steppe soils, designated as chernozem fabric.

* Unpublished experiments on the solubility and decomposition of lignins in soils.

The complexes thus formed are rather coherent in spite of the fact that only a very small quantity of lignin was applied (about three parts per thousand). They retain their shape for some time when placed in water. Their stability would be much greater if comparatively high amounts of NaOH were not deposited in the intergranular braces and films, since this causes solution of the binding lignin to a large extent.

The formation of films on the surface of the quartz grains could be shown more clearly by another experiment in which the 70 mg. of lignin particles were shaken with dilute sodium hydroxide, and the solution brought into the petri dish filled with white quartz sand. Again on the next day the deepest coloration of the sand was observed on the surface. Microscopic investigation showed that only a small amount of lignin was present in the form of grain-like particles. Most of the lignin was found in the form of uniform films. The nature of the films could be made most visible by staining with malachite green; the dye was absorbed to such a degree that the films lost their transparency and took on the appearance of heavy coatings.

Experiment imitating magmoidic fabric. Sodium hydroxide added to a solution of an iron salt causes the normal production of a flocculated precipitation of iron hydroxide. If some sodium silicate (sodium waterglass) were added to the iron solution, the precipitation of iron hydroxide would not occur. J. Bastisse, in Versailles, placed fine quartz sand in a small glass cylinder standing in a somewhat larger glass dish. Some iron solution, protected with sodium waterglass from precipitation by added alkalies, was poured into the glass dish. This resulted in a rise due to surface tension of the liquid in the glass cylinder filled with sand. After some time the liquid had moved from the dish and migrated into the sand cylinder, forming a deeper brown illuvial zone in its surface layer.

A microscopic investigation of the dried sand mass revealed that the whole fabric plasma was entirely peptized. Still, the quartz grains showed no coatings and were united by the peptized intergranular braces which filled a part of the spaces.

The absence of coatings was shown particularly by the debris preparation. On the surface of the quartz grains could be seen deposits of peptized fabric plasma. The surface between the deposits was entirely bare. After washing, the preparation was treated with malachite green by which all deposits were brought out as intense blue-green.

Particularly remarkable was the arrangement on the surface of the undestroyed sand cylinder. The upper parts of the grains sticking out of the complex body were quite bare and striking, due to their white color. The fabric plasma in the intergranular spaces did not quite reach the surface. It came up as far as the narrowest point of the spaces where the curvature of the surfaces of the upper grains came closest together. From above it gave the impression of a tough lava stuck in a rock flue. The menisci, however, were somewhat deeper than normal, obviously formed by partial creeping of the suspension at the margin.

The arrangement corresponds to a soil fabric which will be discussed later as magmoidic fabric. The colloid chemist understands a magmoid to be a solid-liquid (festflüssig) body, i. e., one which behaves in slow movement as a liquid, in fast movement as a solid body. It is characterized by a peptized but comparatively thick-flowing fabric plasma, particularly by increasing concentration in the stages before the drying out of the soil. The genesis of the particular formation has not yet been studied.

3. GENERAL GENESIS OF DIFFERENT FORMATIONS ON THE GRAIN SURFACES

A general explanation of the genesis of the formation of films, coatings, grain deposits and intergranular braces may be given as follows. Due to evaporation taking place on the soil surface the interior soil gradually loses water. The soil solution, which has filled almost all soil spaces after excessive moistening, retires to the angles of the intergranular spaces and to the surface of the grains, forming only a thin coating on the latter. Constituents of the fabric plasma suspended in the soil solution are moved with it. If these constituents were present in the form of larger flocculated complexes there would be room for them only in the water accumulations in the angles of the spaces. They cannot spread out over the soil surface. They are pulled either into the intergranular angles or remain attached somewhere at some point on the grain surface. They form intergranular braces on these places if they are cemented to the soil grains or to each other. They become space deposits if no kind of cementation takes place.

In the case in which the constituents of the fabric plasma are peptized in the soil solution, they are distributed uniformly in the angles and in the liquid coatings of the grains. After drying out, they will form a uniform layer around grains except

in the angles where a larger amount of former soil solution is collected.

If almost no colloids or binding substances are present, and the fabric plasma consists only of rock powder, the latter may be suspended uniformly in the soil solution also. In the dried soil they will be found distributed and adhering all around the grain surface (Bröselhüllengefüge). Here, also, large numbers of particles are collected in the angles of the spaces.

One of the experiments of J. B. Bartlett, cited on page 132, showed that coatings can be formed also by capillary creeping of salt solutions or colloid suspensions. In this experiment the lignin solution poured into the petri dish previously filled with quartz sand, formed films on all quartz grains except those on the surface. These grains remained, for the most part, bare for the first two days of the drying out process. On the third day, however, most of them were covered with coatings. At different stages of these coating formations it could be seen that they were formed by creeping of the lignin on the grain surfaces. The lignin coating formed a system of fine capillaries. Due to the higher evaporation on the upper border of the coating the strongest flow of the lignin solution was in this direction. New layers of deposited lignin were formed constantly by efflorescence and the system of capillaries was thus lengthened for the movement of the lignin solution.

4. SOME TYPES OF ELEMENTARY FABRIC

The following formulation of fabric types is far from being completed. It is just a beginning and, in some cases, probably only a tentative establishment. More detailed investigations have shown that there is an even greater variety in the finer differences of elementary fabrics than can now be described, and this is likely to become more apparent as additional soils from the different parts of the earth's crust are thoroughly examined. The establishment and naming of new fabric types will be justified only if a particular elementary arrangement is found to be characteristic for a particular soil type or subtype.

In view of the difficulties in language, and possibilities of translation, the author followed the example of petrography by using the Greek and Latin language in some cases for the naming of types of elementary fabric. Where English or German expressions are easy to translate, however, they will be used in preference.

PORPHYROPECTIC FABRIC

Description. The strongly reflecting skeleton minerals appear at broken planes, entirely clear and free from coatings, and are imbedded in a dense ground mass showing almost no spaces. Between the ground mass and mineral grains almost no affinity is to be found; the grains easily fall out of the complex. The dried ground mass is often interspersed with cracks. It is of special significance that the cracks go around the soil grains frequently so that the ground mass breaks loose easily from the grains.

In the debris preparations the mineral grains are found almost entirely bare. Surface deposits on the grains adhere only loosely. They are not cemented on it and are easily removed. Beside the grains, fragments of the ground mass are found in great preponderance.

The picture of this arrangement resembles somewhat the picture of the porphyric fabric or the poikilitic fabric of igneous rocks.

Varieties of porphyropectical fabric. (A) The spaces are entirely filled with a mass consisting of very fine, more or less flocculated substances which act as filling but not as binding substances.

The arrangement is found frequently in alluvial soils, particularly those which contain a certain amount of calcium carbonate to flocculate the colloids, but not so much that the lime can act as a cement. The filling substances are washed into the spaces by flowing water.

This is one of the cases in which coagulation is producing, not crumb structure, but the opposite, an entirely dense structure. The floccules are not big enough to be seen as such with the naked eye.

(B) The ground mass appears more or less peptized; it acts as a binding substance in itself but has no affinity for the mineral grains. The cracks in the dried mass often end in a marginal cleft which is formed between the grain surface and the adjacent ground mass. The dry soil is coherent, not because the soil grains are combined by a binding substance, but because the ground mass forms a compact connection in which the mineral grains are loosely imbedded. The ground mass is not pectized in this case; the arrangement has merely a similar appearance to porphyropectic fabric.

Occurrence. Fabric relationships of both variation (A) and (B), as described above, have been found in a number of lateritic red loams. The arrangement of variation (A) can be found in certain alluvial soils or in finely dispersed muck soils rich in calcium carbonate.

Genesis. The term, "porphyropectic fabric," was derived from soils where the flocculated state of the ground mass was more or less evident. It was believed that the lack of affinity between ground mass and the mineral grains always was due to the effect of the pectization (flocculation) of the fabric plasma. This is evident in alluvial soils with flocculated colloids. However, as well as the fabric relationship described as variation (A), relationships of variation (B) also were found in some lateritic soils where the effect of pectization could not be seen by microscopic investigation. It is probable that soils with a fabric showing variation (B) represent younger lateritic soils. The colloidal silica content was always much higher than commonly found in laterites and lateritic soils. The electronegative character of the colloid could be demonstrated by staining with malachite green. It is possible that the silicic acid present in large amounts may act here as a protective colloid for the aluminum and iron hydrates. The matter requires more thorough investigation, especially as to the cause of the lack of affinity between ground mass and mineral grains. A greater number of lateritic soils than has been possible up to the present should be examined.

The soil in fig. 65, a lateritic red loam on lipartic tuff from Kwala Bingei, Sumatra, showed a brownish-red ground mass which, with a microspatula, could be cut easily like a waxy substance. The mineral grains had no coatings and showed a strong glass-like reflection. In the debris preparation they were colorless; treated with malachite green they showed smears of an intense blue-green on their surface. The staining of the smears could not be produced with congo red. The fragments of the filling mass were also intensely stained by malachite green.

Short heating of a small specimen with hydrochloric acid (1:3) dissolved a great part of the iron compounds. After filtration, the almost white precipitate showed colorless, jelly-like gel packets. After removing the acid, a part of every gel packet could be stained with malachite green, while a part remained unstained. A much greater part could be stained with congo

red. By igniting with cobalt nitrate, well outlined sections of Thenard's blue could be produced. In the gel packets a great number of mineral fragments were present which appeared clearly as points of light between crossed Nicols.

PORPHYROPEPTIC FABRIC

Description. The mineral grains are cemented into a dense ground mass. When isolated, they almost always show adhering colloids on the surface as if they were coated (fig. 66).

Occurrence. This fabric type is found in desert crusts, in some Mediterranean red earths, and in illuvial horizons of some podsols.

Genesis. The ground mass consists mainly of colloids in peptized state which have a marked affinity for the surface of the soil grains.

A desert crust on the surface of rocks or cemented soils shows, under the microscope, dense dark-colored accumulations of colloids on the highest points of the microscopic relief. The crust on these points is shining and wax-like. The debris preparation of the material of these points, of a desert crust on sandstone near Gillette, Wyoming, showed all mineral grains surrounded by toughly adhering orange-colored colloid masses, which could be stained an intense blue-green with malachite green. The reaction of suspensions of the colloid mass was alkaline.

The action of colloidal silica as a protective colloid may be observed also in the case of some very dense red earths showing porphyropeptic fabric. The plasma substances are intense red in color, generally forming very tough, hard masses which have a waxy appearance under the microscope, and which can be cut like wax with microtools. The mineral grains imbedded in them are almost entirely invisible. The whole ground mass is stained intense blue-green color by malachite green.

Porphyropeptic fabric was reported in the illuvial horizons of a ground water podsol in Rumania by Christache V. Oprea (15). The soil profile, situated near Pantelimon Ilfov, showed, at a depth of about 35 cm., a whitish-gray horizon of extreme toughness. On microscopic examinations it could be seen that the soil grains were cemented in a wax-like, shiny, dirty white-colored ground mass locally tinted with ochracious shades. Since most of the substances were light colored or almost without color in microscopic preparations,

the nature of the fabric was not so striking as shown in the ordinary debris preparation. The marked affinity of the ground mass to the mineral grains became very evident, however, in the ignition preparation. The ignited debris appeared as an intense orange-red color, indicating that iron colloids were present in the soil mass in the form of ferrous compounds. The mineral grains were covered with parts of the ground mass cemented to their sufaces. The ground mass was peptized, but on examination under high power in the dry state exhibited laminated structures and a very fine granulation in its interior. In thin layers the orange-red marks were ochracious in color.

INTERTEXTIC FABRIC

Description. The mineral grains appear bare and free of coating. They are united with each other by intergranular braces or are imbeded in a porous ground mass of flocculated or crumbled colloids (fig. 67). In soils particularly poor in skeletal material, the uncoated grains are cemented into a ground mass showing cavities of many shapes.

In the debris preparation, uncoated mineral grains showing surface deposits and fragments of intergranular braces are seen.

Variations. (A) The fabric plasma is dark brown to blackish in color and consists of blackish particles of humus, coagulated inorganic colloids, fine rock fragments, and a peptized brown humic substance which is almost insoluble in water but soluble in dilute alkalies. The same humic substance is found in the form of a brownish film around the mineral grains. This variation is designated as chernozem fabric.

(B) The fabric plasma consists mainly of brown to yellow-colored, mostly coagulated inorganic colloids. Compared with those in variation (A) the intergranular braces are considerably less stable in water.

(C) The intergranular braces are formed of flocculated colloids, mineral fragments and insoluble splinters of humic substances, interspersed and united by lime accumulations. This variation will be described in detail in a special paragraph on the fabric of some Austrian muck soils.

Occurrence. Intertextic fabric of the variation (A) is to be found in chernozems, chestnut brown soils, and brown and gray earths of the semi-deserts. Agriculturally, it is the best type of component arrangement. The slow solubility of the

peptized fraction of humic substances explains the great stability of the aggregations and wall bodies of chernozems.

Intertextic fabric of the variation (B) is found in most of the brown and gray-brown earths of the humid regions, and also in many lateritic soils.

Chernozem fabric sub-variations. The intertextic fabric of the chernozems, chestnut brown soils, and brown earths of the desert steppe varies somewhat according to the soil type, as indicated by Christache V. Oprea in his studies of soils formed on loess in Rumania. Oprea describes the differences as follows:

The debris preparation of the desert brown earth showed humus films as well as grain deposits. The grain deposits, however, were much denser, so that they appeared, in many cases, almost like coatings. The intergranular braces and grain deposits were strongly interspersed with salt accumulations with a high content of calcium carbonate. By treatment with dilute hydrochloric acid, all complexes of fabric plasma fell apart rapidly and entirely. Humic substances were present more in dissolved form than in the form of leaves and scales. In spite of this the fabric was less stable in water.

The chestnut brown soil showed fewer but thicker grain deposits in which more leaf-shaped humus occurred than in the brown earth. The intergranular braces were less interspersed with salts; therefore, the union was stronger, and the complexes fell apart less as a result of treatment with hydrochloric acid. Their stability in water was also greater.

The debris preparation of the so-called chocolate-colored soil of Rumania showed grain deposits which consisted of crumbled, blackish, somewhat granulated humic substances which were imbedded in yellowish aureoles of highly peptized humic substances. The grain surfaces were covered by brownish films. Most of the complexes were remarkably stable in water.

Similar grain deposits of blackish and granulated elements were also shown in chernozem. The aureoles and films were brownish. Almost all complexes were stable in water.

Genesis of chernozem fabric. As indicated on page 132, chernozem fabric is produced because most of the inorganic and organic colloids are flocculated or in an undissolved state, although some of the humic substances are dissolved or peptized in the soil solution. The latter act as binding material in the dry soil. Since these humic substances cannot be dissolved in

water experimentally, but can be dissolved in diluted alkalies, the mineral grains and flocculated deposits are combined with each other in such a way that the alkaline soil solution, concentrated in the last stages of drying of the soil, is able to dissolve the substances which act later as binding material. That the soil solution in some stages is able to dissolve a part of the humic substances may readily be seen from the fabric of the chernozem aggregations which will be discussed later.

The more alkaline a humus soil may be in reaction, the more humic substances we can find dissolved. This may be seen by comparison of thin sections of soils different in alkalinity. That the substances soluble in alkali are not lignins can be shown by treatment with acetyl bromide which dissolves lignins quite rapidly, but attack only very slowly the brown-colored binding substances in the chernozems.

Intertextic fabric in brown earths (Braunerden). The central European brown earths and the gray-brown earths of the humid regions of America show mostly intertextic fabric. Most of the fabric plasma appears in typical flocculated state. The grain surfaces between the deposits are almost bare. There is no film formation around the mineral grains. The appearance of characteristic aureoles, however, in which the grain deposits are imbedded, indicates that a part of the colloids must have been dissolved or peptized temporarily. The binding substances are much less stable in water, and the complexes lose their shapes much more readily than do the complexes of the chernozems.

Fabric of calcareous muck soils in summer dry climate. It was indicated by Georg Hardt (Vienna) that many muck soils in summer dry climate show intertextic fabric. Such muck soils developed in the southern Viennese Basin showed, in the debris preparation, mineral grains with crumbly deposits of blackish humus particles. The deposits were interspersed with lime acumulations. Among the inorganic colloids, silica was much in preponderance and could be found in great abundance throughout the soil. Staining of aggregations, fragments and debris with malachite green (after removal of the organic substances by ignition) showed that the accumulations, efflorescences and concretions of lime particularly were covered with finely flocculated silica layers (1).

The accumulation of silica could be shown also in ignited debris preparations which were lightly washed with dilute hydrochloric acid and treated with ammonia. After removal

of the ammonia by slight heating, nearly all deposits took the dye and appeared as a very intense dark green. In only some cases, in which a larger amount of iron hydroxide was present, did the color turn to a more yellowish green. The potassium ferrocyanide reaction showed that the iron colloids were flocculated in a manner similar to the silica. By treatment with congo red only local staining could be observed. Here, also, the stained substances appeared in a flocculated state. The shape of the humus particles could be seen best in the charred preparation. They were mostly present in form of splinters and scales. The grain deposits varied much in shape, thickness and color. In some places calcium carbonate accumulations were preponderant. The shape of the crystal formation could partly be recognized, showing outlines of very small rhombohedrons. By treatment with dilute hydrochloric acid the deposits were partly removed from the grain surfaces and floated in the liquid in the form of more or less coherent flakes.

Elementary fabric and resistance to wind erosion. The muck soils investigated by G. Hardt were characterized by their strong inclination to lose their coherence on the soil surface in the dry summer period, and to change into a very loose material which could easily be carried away by the wind. Every year, this property causes very severe damage to cultivation and is a constant danger to the farmer growing sugar beets. The microscopic investigation of the windblown material shows a picture similar to that obtained by a debris preparation; the intergranular braces, mostly undestroyed as such, are broken off and separated from the mineral grains.

G. Hardt showed by comparative chemical and physical investigations on soils subject to wind erosion on the one hand, and resistant to wind erosion on the other, that neither the grain sizes nor the amount of humus, nor even a change in the nature of the humus substances by heating and drying, had any appreciable influence on erodibility by wind. A very marked influence, however, was due to the lime content, especially in the clay fraction (particles smaller than 2 μ obtained by mechanical analysis). The lime content of the clay fraction of the windblown soils was 20-50 per cent higher than in soils resistant to wind erosion. The statements could be confirmed by rigidity tests with a pressure apparatus.

Microscopic investigations showed that the main binding substance was calcium carbonate which proved to be a minor

binding material in soils showing intertextic fabric. The muck soils investigated were characterized by excessive water content in the cold and wet season, while in the dry summer period they dry out almost entirely. The fabric analysis showed a strongly marked movement of the calcium carbonate from the subsoil to the surface layer where it was deposited in the form of efflorescences on the soil surface, in the soil spaces in the interior of the surface layer, and in the form of interspersions in the fabric plasma. In these illuvial zones the intergranular braces and grain deposits became lighter in color; the precipitation of calcium carbonate took place in the form of flowery elements or minute crystals, which had a loosening influence on the complexes.

In addition to the above explanation of the loosening effect of the lime precipitation, it may be mentioned also that salts crystallizing out of the solutions are able to burst open solid bodies similar to the effect of freezing water. It is a matter of fact that the growth of crystals can overcome considerable resistance as shown by the splitting effect of salts on rocks infiltrated with salt solutions in desert regions.

CHLAMYDOMORPHIC FABRIC*

Description. Every mineral grain is surrounded by a uniform colloidal coating. The grains are generally united into coherent, but very fragile, complexes. The complexes are produced by the growing together of the coatings at the points where the grains touch each other, forming a ring-shaped thickening caused by the larger acumulation of fabric plasma in the space angles. The intergranular spaces are generally entirely empty (fig. 68).

The debris preparations show only coated mineral grains and no fragments of intergranular braces or space deposits.

The presence of coatings around the mineral grains in some soils was observed by many investigators long ago, for instance, by P. E. Müller (38). J. Dumont in Paris, (39) was of the opinion that coatings occur in every soil. He explained that the formation of aggregations in soils is possible only if the mineral grains have coatings so they can adhere to each other. Aggregates which consist of uncoated mineral grains cannot form sufficiently coherent and stable complexes.

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* From Greek: $\chi\lambda\alpha\mu\upsilon\delta os$ = mantle, cloak, sheath.

A. Demolon and S. Hénin (Paris) stated, in objection to this, that the most stable aggregations, as may be found in chernozems, have no coatings but flocculated accumulations of colloids between the soil grains. (40).

Occurrence. Chlamydomorphic fabric can be found in illuvial layers of sandy humus or iron podsols particularly. It occurs, furthermore, in some sandy ground water soils of more or less acid reaction, the soil solutions of which contain large amounts of dissolved iron or manganese compounds.

Genesis. Coatings are produced where all colloid or plasma substances in a soil have been present in the peptized state or true solution. The formation of coatings is only possible if the soil has dried out from time to time, as a result of which the soil solution is forced to retire in a more concentrated state to the surfaces of the mineral grains in the form of adhesion water. Genuine chlamydomorphic fabric will be found only in sandy soils showing a large preponderance of skeletal material and a comparatively dilute soil solution. The growth of the coatings is due on the one hand to the easy and uniform deposition, and on the other to the much more difficult re-solution of the coating substances. The procedure of the formation of the coatings in general was discussed on page 134.

The picture in fig. 68 shows mineral grains of the illuvial horizon of a humus podsol near Dorum, Bezirk, Bremen, Germany. The grain surfaces are covered by a dark brown coating which shows numerous cracks caused by drying. On slight heating and charring, the sections of the coating between the cracks shrink considerably. After ignition the sections are shrunk to about one-half of their original size. Their color is whitish, by stronger magnification slightly yellowish. On treatment with malachite green the ignited sections remain almost entirely unstained. On treatment with congo red, however, an intense coloration results. Sometimes the whitish sections appear deposited on a yellow-red film of iron oxide. Accumulations of iron oxide also can be found deposited in cracks and depressions of the grain surface.

Many dried ground water soils show coatings of iron hydroxide. The original coatings of a groundwater soil near Neuhof of the Marchfield, in Lower Austria, had an intense orange-red color. Before ignition, they could be stained a dark green with malachite green. After ignition, however, they remained practically unstained by the same treatment. The

ignited preparation showed charred spots, and sometimes a charring of the whole coating could be noticed. The staining with malachite green before ignition was caused by the presence of organic matter in the coatings, evidently substances which had been dissolved in the soil solution and organisms, both of which were deposited on the grain surfaces after evaporation of the soil water. The coatings consisted of almost pure iron hyroxide, produced by oxidation of ferrous compounds present in the dissolved state in the former soil solution.

The same soil showed, in other zones of the soil profile, almost opaque blackish-brown coatings of manganese hydroxide. In other parts, coatings of manganese hydroxide, of iron hydroxide (generally in the minority), or of a mixture of both could be noticed.

PLECTOAMICTIC FABRIC*

Description. The mineral grains are entirely imbedded in peptized fabric plasma which forms not only coatings, but also intergranular braces. In soils particularly poor in skeletal material the coated grains are cemented in a ground mass showing many-shaped cavities. The cavity walls exhibit, in many cases, a shiny surface layer (fig. 69).

Occurrence. Plectoamictic fabric is found mostly in the illuvial horizons of iron podsols and podsolic brown earths. Furthermore, in many soils which show porphyropeptic fabric there also can be found plectoamictic fabric in some parts where the fabric is less dense. In this case, the plectoamictic fabric may be looked upon as a preliminary stage of the porphyropeptic fabric. A similar arrangement may be found also in some ground water soils rich in iron compounds and clay substances.

Some red earths and brown earths in limestone show a fabric which represents an intermediate position between the intertextic and the porphyropeptic fabric.

Genesis. Plectoamictic fabric may be formed if most of the colloids were in a peptized state, particularly in those cases where the fabric skeleton is slightly in excess of the fabric plasma or, sometimes, even if the reverse is the case. The evaporating soil solution, rich in peptized colloids, forms

*From Latin: plecto=interwoven (used as a prefix); amictus=coated.

coatings after retiring to the grain surfaces; the colloid substances will be deposited next in the angles of the spaces, forming intergranular braces instead of a mere thickening of the coatings at these places. Coatings and intergranular braces grow by continuous influx of plasma substances and continuous drying and deposition. Finally, cavities are formed which tend to develop a more rounded shape. The walls of the cavities grow towards the center of the empty space.

In order to give an example of this arangement, the elementary fabric of the illuvial horizon of an iron podsol near Pilsen in Bohemia may be described. Its mineral grains were united by means of ochraceous coatings and intergranular braces in such a way that a great number of many-shaped spaces were formed which showed dense wall formations with smooth and shining surfaces. In some larger spaces the smooth shiny surfaces were much darker in color, evidently showing a composition different from the interior of the coatings and intergranular braces. On cross sections against the margin a deep brown coloration of the plasma substances is found, indicating a more densely constructed marginal zone. Mineral grains projecting from the wall complex into the space were less coated, and therefore lighter in color, sometimes almost whitish. Round-shaped zones of deep brown color, which indicated the accumulation of iron colloids, could be seen also in the interior of the wall complexes.

The debris preparation showed that the grains were mostly covered with thick coatings. The more or less homogeneous plasma substance had the appearance and deep ochraceous color of rosin. When investigated with high magnification it showed a fine granulation in the interior. With malachite green it was generally stained a uniform blue-green. In the presence of larger amounts of iron hydroxide a yellow-green color was sometimes obtained. In cases in which iron hydroxide was in preponderance the substance remained unstained. With congo red only a slight change in the original ochre of the iron hydroxide color could be obtained, giving it a more orange tint. Very small parts of a pronounced red color could be observed only sporadically.

AGGLOMERATIC FABRIC

Description. The mineral grains are entirely bare and show at the most only sporadically crumbly, loose and easily removable deposits. All substances of the fabric plasma are

present in a flocculated state or represent insoluble bodies. They are generally to be found only in the form of loose space deposits (fig. 70). A formation of somewhat coherent complexes or aggregates takes place only sporadically or cannot be found at all. Therefore, material of this type often gives rise to windblown soils.

Occurrence. Typical agglomeratic fabric was found in a number of sandy prairie soils in northwestern Minnesota. One of these prairie soils, near Richdale, had a surface layer which was very easily eroded by the wind. In this layer the strongly reflective mineral grains were almost entirely bare and glass-like. In the intergranular spaces somewhat coarse, brownish-gray to blackish-colored, loose deposits were found which consisted of flocculated colloids interspersed with silt particles. In the deeper layers of the humus horizon a slight tendency toward aggregate formation could be observed, though the arrangement was similar to that in the surface layer. The surfaces of the mineral grains were frequently spotted with silt particles which were easily washed out of the space deposits where they were not held by binding substance.

Agglomeratic fabric may be found in many windblown humus soils, also in the surface layer of the calcareous muck soils mentioned in the paragraph concerning intertextic fabric.

Genesis. The general genesis has already been discussed with reference to the description of the experiments imitating agglomeratic fabric (p. 131). Agglomeratic fabric generally occurs only in sandy soils under special circumstances. These sandy soils would not be so open to wind erosion if they were built up another way such as is demonstrated by the coherent and stable complexes produced by J. Bartlett's experiments with lignin solutions and quartz sand.

The formation of agglomeratic fabric in the surface layer of calcareous muck soils well dried out in the hot season is due to the loosening effect of the precipitation, and crystallization of accumulated calcium carbonate as described on page 142.

BLEACHED SAND FABRIC

Description. The bleached horizons of podsols show by microscopic examination, in many cases, some raw humus between the mineral grains. If the raw humus particles are present to some extent, the picture of the fabric may resemble the agglomeratic fabric. The mineral grains are entirely naked. The space deposits of humus, however, contain resi-

dues of plants with structures preserved, particularly roots and root hairs. In the splits and dents of the grains, accumulations of peptized colloids may be found by examination of debris preparations, particularly when higher magnifications are used. They represent residues of former coatings which are preserved in places and more protected against washing. Sporadically, parts of the coatings or almost undestroyed coatings covering the whole grain surface may be found. By ignition of the humus particles, residues of inorganic colloids which were accumulated in the pores of the plant residues and thus protected from being carried away by the soil water, may be noticed.

Occurrence. Bleached sand fabric similar to the above description generally occurs only in humus podsols. In iron podsols, in most cases, only residues of coatings or some remaining accumulations of inorganic colloids, mostly iron hydroxide, are found in the more protected cracks and dents of the grain surfaces.

Figure 71 shows a debris preparation of the whitish-gray-colored layer (4-10 cm.) of the humus podsol near Dorum, Bezirk, Bremen, mentioned on page 144. The mineral grains consisting of glassy quartz throughout the soil were almost entirely bare. Only some parts showed almost red-colored accumulations of colloids in the irregularities of their surfaces. Dark brown coatings, or parts of them, could be seen in only very rare cases. The humus deposits in the spaces consisted, in general, of leaf-shaped, sepia-brown tissue fragments which were much shrunk together. Soaked in water and prepared in the wet state they showed, in most cases, the original cell structures. Furthermore, somewhat reddish-colored, wooly remnants of plant roots were to be found. After ignition, the humus particles showed, in all cases, brownish-red, and by higher magnification yellowish-colored residues of inorganic colloids. They could be stained as well with congo red as with malachite green.

Genesis. The difference between the bleached sand fabric and the agglomeratic fabric lies chiefly in their genesis. In the case of the first type, soil constituents of originally coated mineral grains were washed out. The colloid coatings were so far removed in most cases that only very minute residues remained in the cracks and dents. In the case of the latter type, the lack of coatings is due to the lack of peptized colloids.

RENDZINA FABRIC

Description. The mineral grains are bare and, in debris preparations, show no films and almost no surface deposits. Many of the mineral grains are calcite. They are embedded in a loose ground mass of humus particles. There is almost no binding substance to unite grains and humus particles. The grains fall out of the complex easily. Fine sand and silt may be easily carried away by the soil water and frequently may be found deposited in large numbers on the wall surfaces of the larger soil spaces in the dried-out soil. Also, the humus particles of the ground mass show no binding between one another. They are loosely combined, the whole fabric being held together only by the interlocking of the splinter-like particles. The fabric of the humic ground mass is more stable in the wet stage, while the smaller mineral grains are easily washed away. In the dry state the humus particles become very friable, the complexes fall apart very easily and may be dispersed by slight friction into a blackish powder.

The humus particles show, in almost all cases, their original structure as plant residues. They generally consist of reddish-brown to ochraceous-brown (in thin sections translucent) interior showing original plant cell structures, and an outer layer of blackish to dark brown, crusty, opaque, sometimes coal-like substances. In many cases, efflorescences of these substances may be found in the form of protuberances on the surface of humified stem or root fragments or even on the surfaces of space walls. Similar bodies shrunk together and somewhat broken up may be found removed from their positions and distributed throughout the soil.

Occurrence. The arrangement occurs with some variations in rendzina soils. Humus-carbonate soils of the same fabric and the same fabric constituents were found by the author not only on limestone, but also were observed on dolomite in Austria, on dolomite and silicious limestone in eastern Iowa, and, furthermore, even on crystalline schists rich in lime (Kalkglimmerschiefer) in Austria (Glocknergebiet). They do not cover large areas on these rocks but occur only locally.

Genesis. The rendzina is characterized by the fact that the peptized, chernozem humus fraction stable in water and soluble in alkali, and the highly hydrophilic acid humus fractions of the podsols soluble or highly dispersible in water, are both practically absent in the process of soil formation. They can-

not be discovered as fabric units by fabric analysis. This property is due to the fact that rendzinas are formed on limestone or calcareous rocks in pronounced humid or podsol climates. The humid climate suppresses the formation of the alkali soluble humus fraction of the chernozem. The presence of large amounts of lime prevents the formation of acid humus. When lime is entirely removed from the soil, acid humus is formed. Its action as a protective colloid is made possible and podsolization of the rendzina begins.

Of particular interest is the blackish-colored, opaque humic substance produced in the form of crusts and many-shaped efflorescences on the surface of humus particles and plant residues. The fact that they are efflorescing indicates that they occur temporarily in a dissolved or peptized state inside the plant residues or humus particles. The absence of films on the mineral grains, however, indicates that they are not present in a dissolved state in the soil solution. A real knowledge of the relations and microdynamic processes of this extremely interesting soil type will be obtained only by further detailed investigations.

MAGMOIDIC FABRIC

Description. The naked mineral grains are combined by intergranular braces, generally of ochraceous to orange-red, peptized inorganic colloids. Formations of films, coatings or flocculated deposits are almost entirely absent.

The most important features of the debris preparation are the sharp-edged fragments of intergranular braces and the bare mineral grains with peptized inorganic deposits. Of significance, also, is the formation of many-shaped tongue-like irregularities on the marginal contours of the deposits or residues of intergranular braces on the grain surfaces (fig. 72).

The fabric generally is very unstable in water. By washing a suspension in water the grain deposits are in many cases easily removed. The material obtained consists of entirely denuded grains and residues of intergranular braces which are changed to more or less round-shaped complexes as a result of the washing away of their edges (fig. 73).

The name "magmoidic fabric," explained on page 134, was given to this arrangement because of the magmoidic state of the fabric plasma in those stages of the soil in which the fabric originally acquired its characteristic features. Details of the fabric which indicate the temporarily magmoidic nature

of plasma substances are to be found in fabric members of higher order more than in the elementary fabric as will be shown later.

Occurrence. Magmoidic fabric was found in some Mediterranean red earths. It was observed first, however, in the B-horizon of some intense dark ochraceous-colored soils near Versailles, in France. The soils were named and mapped as brown earths. Microscopically, however, they differ so greatly in their dynamics, constituents, and fabric arrangement that they form a type of their own, resembling the degraded yellow earths of the southeastern United States. A detailed study of one of these soils in the "Sablière" near Versailles was begun by the author in the summer of 1935. The work will be continued with American soils.

Genesis. The fragments of the illuvial horizons of the sandy soil of the "Sablière," in their extreme hardness when in a dry state, resemble rocks. On slight moistening, however, they lose their coherence very rapidly and fall apart. After ignition the fragments are not only stable in water, but also resistant when treated with dilute acids and alkali.

The main binding substance in the soil fragments is a form of colloidal silica, which is so easily soluble in water that it may be obtained by evaporation of a filtrate produced by filtering a soil suspension which has been shaken for a few minutes in a shaking apparatus. It may definitely be seen by microscopic investigations that the silica is acting as a protective colloid for the iron hydroxide and probably, also, in a similar way for the aluminum hydroxide, as was indicated by Reifenberg in Mediterranean red earths. The colloid fraction, although entirely free of acid humus substances, is dispersed so easily in water that the soil develops a whitish-gray, bleached horizon at a depth of 35-45 cm., consisting, in the main, of more or less naked mineral grains. The eluvial process could be observed even by microscopic investigation on soil clods exposed to the rain. These clods developed eluvial zones on the upper surface, and well marked illuvial zones showing accumulation of the colloid fraction on the lower surface.

To what particular processes the arrangement of the elementary fabric is due cannot be decided because of the lack of detailed data. It may be derived from the magmoidic nature of the fabric plasma produced by the higher contents of active and water soluble silica, or it may have originated because the coatings or smaller deposits are easily removed by washing as

could be seen by the investigation of washed debris preparations mentioned above. Both possibilities may prove to be right.

MORTAR FABRIC

Description. This fabric type occurs mostly in connection with plectoamictic or intertextic fabric. It differs from both in that the intergranular spaces contain a crusty or flowery white mass. It consists, in the main, of very small (generally only 1-2μ) round crystals of calcite. In larger spaces the microcrystals cover the surface of the space walls (fig. 74).

In the debris preparations, coatings (or grain deposits) and intergranular braces are found covered with microcrystals, and also fragments of the lime accumulations which had been growing into the interior of the air-filled soil spaces. The microcrystals, seen with higher magnifications, are grain-like, colorless, and transparent. In some cases they show in definite but visible crystallographic contours.

The name "mortar fabric" was chosen because it resembles very much the fabric of a dry and cured mason mortar. In both cases the storage of complexes of microcrystals of calcium carbonate are observed. If a yellow sand consisting of coated quartz grains should be used in the manufacture of mortar, the similarity of the fabric picture would be so close that it almost could not be distinguished from the microscopic picture of the lime horizon of a Central European brown earth.

Occurrence. Mortar fabric may be found in the lime horizons of brown earths, podsolic brown earths, chernozems and calcareous ground water soils.

Genesis. The microcrystals are formed largely by an efflorescence process and only in a few cases, mostly in ground water soils, are they formed by direct precipitation and sedimentation from the evaporating soil solution.

The calcium carbonate is transported by the soil solution in a dissolved state in the form of calcium bicarbonate, into the deeper horizons of the soil profile. The evaporating soil solution retires to the pores of the fabric plasma. By continuous drying of the plasma substances the dissolved lime begins to effloresce in the form of calcite on the surface of the intergranular braces and coatings. If the concentration of the soil solution is lower, the efflorescence will take place in the form of very thin but long needles as will be shown later. If the soil solution reaches a high concentration of dissolved salts, then

the efflorescences will be formed as very small round crystals. Precipitations of these microcrystals will be found not only on the surface, but even inside of the fabric plasma, i. e., in the intergranular braces and coatings. These interior precipitations make the fabric plasma appear lighter in color. By treatment with dilute hydrochloric acid all intergranular braces or coatings effervesce and fall apart.

The formation of the lime accumulations could be studied in all its stages on a brown earth on loess near Altenhof, Lower Austria. Soil samples in an undisturbed condition were taken in the moist state from the lime horizon which was found at a depth of 110-130 cm. The samples were taken to the laboratory and the changes due to drying observed microscopically. Under the microscope the fragile, whitish-ochraceous soil mass showed, on freshly torn planes, whitish areas which were filled with large quantities of lime efflorescences, as well as dark ochraceous-colored parts which showed almost no efflorescences. The surfaces of the dark ochraceous-colored space walls were covered in a short time with microcrystals which could be observed microscopically growing out of the colloid pores. The growth began on the highest points of the micro-relief of the wall surfaces. The efflorescences covered the whole surface in a few minutes, but the growth did not stop. The white layer, consisting of a large number of crumbly complexes of microcrystals, gained in thickness and developed into the empty space. From the appearance of the growing crystal complexes in the dry state, and from the observations of the efflorescing process in its earlier stages and the formations of the first crystal complexes, it may be concluded that the efflorescences are developing on the original wall surface and not on the new surface of the lime accumulations. The old crystals are pushed away from the wall surface by the newly developing efflorescences. The small crystals adhere to each other in the first stage when they are not entirely dried. The crumbly complexes still may be seen in all debris preparations of the horizon.

CHAPTER III

Fabric of Aggregates and Cleavage Blocks

Fabric members of higher order. Fabric units of higher order may be found combined in a single and coherent body such as a soil horizon. Moreover, a soil or soil horizon may consist of an arrangement of numerous smaller bodies. These bodies, subordinated to a larger soil part such as a soil horizon, may be either aggregates or cleavage blocks. Aggregates are to be found only in loose soils, though not all loose soils or soil horizons form aggregates. Cleavage blocks (Absonderungskörper) are formed in compact soil horizons which have been divided into numerous portions showing characteristic sizes and shapes by the drying and shrinking process.

Aggregates, fragments. The first to use the term "aggregate" for the characteristic grain complexes in soils was J. Dumont (39). In the present mechanical aggregate analysis, a counterpart to the mechanical analysis for the determination of the grain sizes, the term "aggregate" is used for any grain complexes stable in water or other media, or fractions of any kind of grain complexes which may be obtained by the application of sieves to dry samples of soils.

Fabric analysis deals only with the microscopic investigation of natural fabric formations of soils. Therefore, grain complexes as they can be obtained after treatment with liquids or after rough mechanical procedures are not to be included in a classification of naturally formed fabric units. On the other hand, microscopic investigations show that such naturally formed grain complexes, in the sense of J. Dumont, exist not only in many soils, but also have a definite construction. This construction is different from that of other grain complexes such as fragments or cleavage blocks. There are also great differences between the fabric of aggregates formed in different soil types. They are in some cases a very marked expression of the microdynamics of the soil and, therefore, also of the soil type.

By soil *fragments* we understand grain complexes produced by artificial splitting, breaking or crushing of soil parts. *Cleav-*

age blocks are grain complexes found in dried out compact soil horizons, produced by the natural shrinking and drying processes. *Aggregates* (in the sense of fabric analysis, without prejudice to the use of the same term in mechanical aggregate analysis) are more or less round grain complexes of characteristic construction in loose soils. They are independent formations, well demarked in themselves, which show naturally regulated growth and a definite fabric according to their soil type or subtype.

Formation of aggregates. It was believed in soil science that formation of aggregates was caused by some flocculation process. By microscopic analysis, however, traces of flocculation effects are rarely to be seen in the fabric of aggregates. They are more likely to be found in some of the elementary bodies which fall under the collective term of fabric plasma, particularly in intergranular braces (intertextic fabric), space deposits (agglomeratic fabric) and grain deposits.

Toward the explanation of the first stages of aggregate formation we have very little data. Some aggregates in the beginning may be formed by a mechanism similar to that observed in the formation of cleavage blocks in a soil which is drying out. But in the aggregate formation of many soils, particularly of the humid types, micro-erosion plays an important role. The factor of resistance to micro-erosion determines to a great part the shape and the surface formation of almost all aggregation types. In the mechanism of the formation of the characteristic surface crust of the aggregates various types of efflorescence processes are primarily responsible, much surpassing in importance the processes of micro-sedimentation.

Many aggregates may be formed also by the action of organisms, mainly of earthworms which can produce whole layers consisting mostly of their excretions. They are generally arranged into layers by the soil water and may be partly changed morphologically by surface erosion, surface deposition and efflorescences. The natural process of aggregate formation is much influenced and promoted in agricultural soils by tillage.

In antithesis to the formation of aggregates, in the formation of cleavage blocks micro-erosion plays no role at all while efflorescence still is an important factor. Remoistening of the soil means, in almost all cases, the end of the cleavage blocks; their surfaces grow together, the cracks become more and more closed, and the numerous bodies are united into a single coherent mass again.

Chernozem aggregates. The surface layer of chernozem aggregates is, as a rule, denser, harder and more stable than the interior. In many cases, the surface is found covered by a smooth, shiny protection crust which consists mainly of blackish, highly peptized humic substances. In soils with high sand content this crust is less apparent. The accumulation of the humic substances, however, may be discovered by closer investigation in and upon the surface layer. Small chernozem aggregates are generally globular in shape. Many chernozems, however, contain aggregates with a great variety of shapes and, in the formation of the surface relief, show many-shaped folds and wrinkles. Oprea described aggregates which could be broken open in several layers like onion skins. (15). They were produced by the successive formation of several crusts indicating different stages in the drying out of the aggregates. Steppe soil aggregates surrounded by crusts of humic substances show a much greater stability in water than aggregations of any other soil type.

The last stage of the drying aggregate is the most important in its formation. In this stage the soil solution is most concentrated and most alkaline in reaction, and, therefore, most capable of dissolving the alkali soluble humic substances. The accumulation of these humic substances, in the form of blackish and shining crusts on the surface of the aggregates is due to the migration of the concentrated soil solution in the interior of the aggregates in the direction of their surface. Occasionally it may be seen, however, that these surface crusts are also formed by micro-sedimentation, in some cases from the evaporating soil solution present in the spaces between the aggregates.

The fact that the protection crust is difficultly soluble in pure water or in more or less neutral soil solution is important. This, together with the presence of the particular elementary fabric (chernozem fabric), explains the well-known stability of chernozem aggregates. This stability cannot be explained by the mere fact of a favorable electric charge of the soil particles resulting in flocculation and crumb formations. It is due to the particular humic binding substances present in chernozems.

The humic protection crusts of chernozem aggregates are highly soluble only when the soil solution reaches a high salt concentration and alkalinity by evaporation. In this case, however, no erosion on the surfaces of the aggregate takes place, but an accumulation layer continuously grows and thickens by capillary tension to the aggregate surface. Thus, this stage con-

tributes not only to the conservation of the aggregates, but also to their further development.

Mammillated aggregates. Though the protection crust on chernozem aggregates may always be observed, there are different stages in formation ranging from slight accumulations of peptized humic substances in the intergranular spaces of the surface layer up to the formation of a dense crust covering all grains of the aggregate surface. In extreme cases a development of dense mammiform extuberances is found. Aggregates of this type were found by the author in a chernozem near Tower City, North Dakota. The smaller aggregates of the surface layer of this soil were round, almost globular (diameter up to 200-400 μ). The larger aggregates, which reached a diameter up to 5-8 m/m, showed almost always the formation of mammillae on their surfaces (fig. 75). The development of mammillae took place, not only on the upper and lower surfaces, similar to the formation of stalactites and stalagmites, but in all directions. The top of the mammilla was usually dark gray, shining like graphite, entirely dense and smooth, almost polished. The foot was rough and granulated. Smaller head-shaped mammillae had a height of about 160 μ. Larger and long-shaped mammillae reached a height of 400μ on a base of 500-600 μ. The peptized binding substance was in thin layers, sepia brown and transparent. In dilute alkalies it was dissolved, yielding a brown-colored solution.

The mammillae were developed on the highest points of the relief of the aggregate surface. In the depressions the surface crust was less dense in fabric, rough and granular. In many cases a part of the mineral grains of the surface layer were liberated from the protection crust.

The interior of the aggregates was porous and contained some larger cavities. The intertextic fabric of the interior showed considerable hardness. Fragments could be broken out with a micro-needle only with difficulty and required application of considerable force. The binding mass was gray, shining, dirty, wax-like, and much less interspersed with flocculated elements than generally is the case in chernozem fabric.

The genesis of the mammillae may be explained by the same efflorescing process which forms the humic protection crust of the chernozem aggregates. The capillary tension on the aggregate surface will be the highest on those spots which are most exposed to evaporation, and thus where the highest concentra-

tion of the solution is found. Therefore, the formation of the mammillae is observed on the elevations of the surface relief. The accumulation of colloid substances on these spots causes a lengthening of the capillary system and a rise in the elevation at these places as a result of the capillary tension gradually becoming even stronger. Thus, an extraordinary favoring of these points in regard to efflorescence and accumulation of colloids takes place, resulting in the formation of the long-shaped mammiform extuberances.

Aggregates with granular shells. Microscopic investigations of cross sections of some chernozem aggregates, obtained by breaking them apart with a micro-needle, showed that the complexes had not only a more or less developed crust of plasma accumulations, but also were protected to a considerable extent by a dense shell of mineral particles. These were joined closely to each other like the stones of a wall, the spaces between the grains being reduced to the smallest possible size (fig. 76). It could be observed that the grains were cemented to each other by the same humic binding substance which was found as the main constituent of the surface crust.

As to the gensis of the granular shell, it may be assumed that its formation took place in those stages in which the evaporating soil solution was retiring to the aggregate surfaces. The interior of the aggregate was soaked and softened, the whole representing a more or less pulpy mass, the surface of which behaved like the boundary surface of a liquid. Bodies in the interior, which adhere to the boundary surface of a liquid, tend to touch each other and to be pulled as close together as possible. This may be shown by the following experiment.

In a mortar pure quartz sand is ground to a powder, and the ground material mixed thoroughly with chloroform. A small part of the suspension is taken up with a capillary pipette, and small drops of it introduced into a small flat glass dish filled with water. By microscopic investigation, using a magnification of about 100x, it may be observed that the small quartz grains move from the interior of the chloroform drop to the surface and are arranged here to a complete shell showing almost no spaces between the differently shaped grains (fig. 77). Instead of chloroform, linseed oil can be used and proves even better, though the process is prolonged and takes several hours. As in most of the smaller soil aggregations, formations of globular shape are the most frequent.

The shells of the aggregates in soils in some respects resemble

the shells of certain tecamoebae, mostly constructed of mineral grains, silica shells of diatoms, etc., which cover the body of the animal in an arrangement which leaves no interstices. The experiment described above was first performed by L. Rhumbler (41) in order to imitate the formation of these tecamoeba shells.

The explanation of this formation is found in the fact that irregularly shaped objects adhering to the boundary surface of a liquid produce changes of the surface by bending it outward or inward according to their particular forms. This means an increase of the surface which is opposed by the surface tension forces tending to minimize it. If the resistance of the objects in friction or mobility is not too great, they will then be moved and pushed together to form a dense shell. Thus, a plain surface formed by the objects instead of an enlarged and therefore unstable surface formed by the liquid is obtained.

Aggregates in humid soils. Some Central European brown earths show aggregates of the following construction: The complex is generally composed of a number of small, almost globular bodies from 80-400 μ in diameter which have a dirty brown color and the appearance of globules formed from bread dough or marzipan. The dense surface is not shining but dull. On the upper surface of the globules a number of mineral grains is found protruding. These external grains are entirely denuded, all deposits or coatings having been washed off. Numerous grains of the same appearance also may be found in the spaces between the globules (fig. 78). The surface of the globules contains an accumulation layer of inorganic colloids. This layer, however, is considerably less stable in water than the surface layer of the chernozem aggregates.

Aggregates in podsolic soils are rare. They show a rough and torn or entirely rounded surface. Their upper layer is destroyed and carried away by microscopic erosion.

Fabric of cleavage blocks. Most of the cleavage blocks show a crust formation similar to that which may be observed on the surface of aggregates. Though the morphology and chemical nature of this crust formation is characteristic for the soil type, as are the surface crusts of aggregates, it will be of minor importance compared with other fabric relationships which lead to the formation of a great variety of cleavage blocks (nutlike, prismatic, columnar blocks, cleavage plates). Very few data have been collected hitherto regarding the fabric of cleavage blocks. It may be predicted, however, that future fabric investigations of cleavage blocks will be of particular import-

ance, since they should provide the information necessary for a detailed explanation of the genesis of these formations. Cleavage blocks are highly characteristic in their morphology according to the soil type. Since most of them may be seen with the naked eye, pedology in all countries has particularly taken advantage of this fact in using their morphological differences for the characterization and classification of soils.

CHAPTER IV

Fabric Types in Coherent Soils

Coherent soils are those which form coherent bodies in a dry state. As such they represent formations, the maximal pressure resistance of which varies from a few dekagrams to 120 and more kilograms per sq. cm., and the binding substances of which may reach a hardness of 4 on Mohs' scale. Regardless of their behavior in moistened condition, many of them in the dry state have almost the properties of solid rocks. Coherent soils, especially compact soils, are particularly suitable for the performance of fabric analyses because the component movements, even those which occurred long ago, are well preserved in them and are not destroyed by disturbances.

1. SPONGY SOIL FABRIC

GENERAL FEATURES

Loose soils forming grain complexes will consist in the main of aggregates and complexes of aggregates which have been partly growing together but still are not united into a single coherent layer. Good examples of such soils are shown in the surface layer of some chernozems (showing so-called "fish roe structure" as designated in the Russian literature).

If all aggregates and aggregate complexes become incorporated by fusing with each other we obtain a united coherent soil layer. The many-shaped and comparatively large cavities between the united aggregations are connected with each other and form, altogether, a net which is developed in all three dimensions of the space (German: netzräumiges Gefüge). The grain complexes in these soils differ from the aggregates morphologically in that they are not rounded, but show braces to the neighboring complexes. They not only adhere to them but are combined with them in the same way as that in which the fixation takes place in their interior. Thus, they are parts of a united, cellular body which are broken out of the body and do not represent aggregates in the sense of fabric analysis, but fragments of this body.

The arrangement described above is designated as "spongy fabric." The soil mass is divided by it into two phases, the solid part consisting of wall complexes or wall bodies, and the spaces walled by these complexes. Both are very different in their conditions, not only in regard to processes of inanimate nature, but also in regard to the life and development of microorganisms. The spaces encased by the wall bodies are the favored habitats of many microorganisms, especially fungi and actinomyces which grow and develop fruiting bodies on the wall surfaces, and protozoa, nematodes, and other animals which live for the most part in the capillary and adhesion water of these spaces. They represent, furthermore, the positions where we find most of the autochthonous crystal formations of the soil produced by efflorescence (when the spaces were air filled), or by growth within saturated soil solutions in the case of ground water soils. To demonstrate their function, in contrast to the wall bodies, they may be designated as "sprouting spaces." They are as such not only the favored habitats of the soil life and of microscopic plants growing on the wall surfaces, but also of many striking inorganic formations which are nourished by substances present in the interior of the wall bodies. The migration of these substances to the wall surfaces takes place during the stages when the soil dries out.

The sprouting spaces can be designated also as spaces of the second order. They are differentiated by this term from the much smaller intergranular spaces which are spaces of first order. There is still a possibility of finding spaces of a third order which are mainly produced by animals, by shrinking of the soil mass, by corrosion or by artificial mechanical influence in agricultural soil. Spaces smaller than the intergranular spaces or spaces of the first order are also of great importance in soil dynamics. These are the pores of the colloidal or highly dispersed deposits. They are designated as "pores."

Crust formations on the space walls. As has been shown already with the aggregates, the dynamics of the soil do not consist only in a simple descent or ascent of salt solutions or colloid dispersions, but are much more complicated. In drying soils all substances dissolved or dispersed in the soil solution move in the direction of the evaporating surfaces where they are deposited and thus accumulate. By this process crust formations on the surface of the space walls, similar to those in the case of the aggregations, are produced. The corrosion effect of the percolating soil water in the stages of remoistening of the soil acts

against the formation of protection crusts. Therefore, the stability of the wall bodies and their surface formations and, furthermore, the frequency and the intensity of washing by leaching, are the major factors influencing the fabric of spongy soils. Soils with frequent and heavy washing and low stability of the wall surfaces also show a progressive removal of soluble or dispersable binding substances in the interior of the wall complexes. As a result, the wall bodies finally lose their coherence and fall apart easily.

Types of wall surface formations. The influence of the microdynamics on the kind of wall crust formation may be demonstrated by different examples which, in essence, were formed by conditions similar to those which formed the respective aggregate types.

Figure 79 shows the pattern of the wall complex of a spongy steppe soil. Owing to the preponderance of centrifugal dynamics in the wall body caused by the hot and dry summer periods, we find the accumulation of the alkali-soluble humic substances in the form of a dense, smooth, shiny surface layer. Sometimes the surface appears rough and scurfy, but also in these cases the accumulation of the peptized humic substances may be noticed. The erosion effect of the soil water is less marked in the soil fabric. The wall bodies and surface formations are stable provided the soil is not too alkaline. In alkaline soils the spongy fabric is more easily destroyed because the humic binding substances can be dissolved also in the first stages of the remoistening of the soil.

Figure 80 shows the pattern of a wall complex of a humic soil. Washing by percolating soil water occurs more frequently, the wall complexes are less stable; the microscopic erosion, however, takes place in a form in which the washed walls still show smooth surfaces. Grains of the surface layers are partly exposed. They are entirely washed off and naked portions are protruding out from the wall body. A part of these exterior grains may be found removed and accumulated on projections of the wall relief or on the bottom of the spaces (which may be partly observed also in chernozems, particularly those more alkaline).

If the effect of the percolating water is greater than the resistance to it by the coherence of the wall bodies, then the soil develops to a body which gradually loses its spongy fabric; it becomes compact. By artificial loosening of the soil fabric it is possible to produce a spongy fabric which remains for some

time. However, the complexes soon become fused and are melted into each other after a short period of rainfall. The quicker the soil tends to return to the original compact fabric which corresponds more to its nature, the more often the artificial loosening must be repeated.

Of great variety is the morphology of the surface relief of the wall bodies. Thus, one finds concave forms covered with smooth layers of micro-sediments, wall bodies which are almost entirely convex, surfaces which are folded and wrinkled, surfaces of rough or scurfy appearance, etc. The fact that every soil part characterized by certain conditions possesses a more or less particular surface relief on its wall complexes deserves detailed study.

CRYSTAL FORMATIONS IN SPACES OF SPONGY SOILS

The numerous air filled spaces in spongy soils give rise to manifold crystal formations produced by efflorescence of salt dissolved in the soil solution. In classifying the formations produced by the evaporation of the soil solution the following types, which are of particular importance for soil fabrics, are obtained. If a solution is drawn from the interior of a porous body by evaporation, which results in a precipitation of the dissolved substances on the surface, the process and product is designated as efflorescence. If the concentration of the solution reaches such a height that the precipitation of the substances dissolved in it is produced before they reach the surface, i. e., while still in the interior of the body, we call the process and product interflorescence. If the precipitation is produced on the surface of a fabric body from outside, for instance on the surface of a wall complex from a solution filling the space or adhering to the wall surface, we call it deposition.

Efflorescences. Precipitations produced by efflorescence have obvious roots in the space wall by which they may often be distinguished microscopically from depositions. Furthermore, the preference of the efflorescences for the elevations of the surface relief can be recognized in many cases. The term "efflorescence" is to be understood here in a wide sense, i. e., not only does it include crystallizing salts, but in the same way, colloids, even though they are not precipitated in crystalline form. For many extuberances of colloid gels the term "efflorescence" is also etymologically correct and constructive since they are gradually growing into the air space in long-shaped and manifold formations.

Efflorescences are of exceptional importance in soil fabrics, while in rock fabrics they are of minor significance. This has been shown already particularly in the monograph on efflorescences by K. Schultze. It is explained by the fact that the soil, as the more or less aerated upper layer of the earth's crust, undergoes a continuous cycle of drying and remoistening.

Interflorescences. The process of interflorescence is closely connected with that of efflorescence. Interflorescences are produced when the evaporating soil solution precipitates its substances while they are still in the interior of the porous body. Also, here a pre-existent pattern of skeletal particles is invaded by newly formed plasma substances in the form of efflorescences which are retained in the interior of the capillary system. Many precipitations of substances in pre-existent fabric patterns which have the appearance of interflorescences prove to be efflorescences after more careful investigation. An example of this is found in the accumulations of microcrystals of calcite in the intergranular spaces described in the chapter, "Elementary Fabric," under the heading of "Mortar Fabric." These crystals are found efflorescing from the surfaces of the colloidal coatings or intergranular braces. The precipitations in the interior of these parts of the fabric plasma, however, which became lighter in color and which effervesced with dilute hydrochloric acid, represent a typical case of interflorescence. Interflorescences in the fabric plasma may cause a considerable loss of the solidity of the complexes as was shown by G. Hardt (p. 143). Whether efflorescences or interflorescences are formed in the capillary spaces of a porous body depends very much on the size of the spaces and the degree of their infiltration by the soil solution.

Depositions. Sedimenation in microscopic dimensions takes place not only downwards, but also laterally or upwards in the direction of a space wall under the influence of the attractive forces emanating from it. Micro-sedimentation may be either mechanical or chemical. By it a separation of the particle sizes and substances different in composition and properties also may be produced, resulting in the formation of different layers. Deposition is created, not only by micro-sedimentation, but it also may be caused by the evaporation of liquid coatings on the surface of a body from which the dissolved substances are liberated.

Accumulations of substances formed by deposition may, in most cases, be distinguished from efflorescences in that we

find it is not the elevations of the surface relief which are favored in the formation of accumulations, but the depressions. There is a tendency to equalize relief differences. In soil spaces we frequently find the development of more or less concave wall formations which are covered with a smooth, shiny, almost lacquer-like layer. In tubular and cleft-shaped spaces flow structures may be preserved on depositions.

Many interspersions of pre-existent skeleton patterns by plasma substances originated in the form of depositions which gave rise to the formation of a number of types of elementary fabric described in Chapter II. Thus we can designate chlamydomorphic fabric, plectoamictic fabric and even intertextic fabric as mainly caused by deposition, while porphyropectic and porphyropeptic fabric in surface layers may be caused by interflorescence.

Deposition, efflorescence and interflorescence may be marked in the fabric at the same time since in the last stage of the drying process every accumulation is completed by efflorescence or interflorescence. In some cases a recognition of the nature of these terminal formations may be difficult.

Types of crystal formations. In view of the great variety of crystal formations of the same salt, including those which are not formed by efflorescence, one is led to search for the particular conditions under which they are formed. They are caused by the most diverse circumstances, such as the size and shape of the spaces, the air and water content, the concentration, reaction and composition of the soil solution, the nature of the capillary system, and the presence of certain substances, especially colloids, etc. Concerning the influence of colloid gels on crystal forms there are a number of studies and experiments performed by investigators in the field of general colloid chemistry and capillary physics. Likewise, as observed in soil fabrics, salts crystallizing from gel masses do not form the common crystal types as produced under normal conditions, but peculiar shapes of needles, thorns, threads, parasols, triangles, stalagmites, powdery precipitations, etc. Some of the most frequent and important occurring in the spaces of the second order in spongy soil fabric will be discussed in the following paragraphs; some other crystal formations produced in spaces of compact soils in absence of a direct influence of evaporation will be described in a later chapter on compact soil fabrics.

NEEDLE-SHAPED CRYSTALS OF CALCIUM CARBONATE

Description of needles and locations in brown earths. Needle-shaped crystals, probably mostly calcite, may be found quite frequently in Central European brown earths and in chernozem. Calcite needles of a brown earth on loess near Fernitz, Lower Austria, studied by the author, had a diameter of 1-1.4μ. Only in rare cases did they reach a length of more than 50μ (fig. 81). Sometimes colloid deposits adhering to them were to be observed. The needles occurred in the intense brown-colored B-horizon at a depth of 40-60 cm. and were generally found in larger spaces with smooth space walls. The soil showed no effervescence with dilute hydrochloric acid. The pH was 6.6.

It is essential to know that the A-horizon with a depth of 10 cm. and a pH of 6.2 showed no kind of lime efflorescences, while in the whitish-ochre B_2 horizon flowery precipitations of microcrystals took the place of the needles. The pH of the latter was 7.5. The fabric of A, B_1 and also partly of B_2 was spongy; the fabric of C was compact. In the C-horizon all larger spaces were filled with larger crystals of calcite, which indicates that they were not efflorescences but formations developed in the soil solution. The C-horizon also was pierced with a large number of crystal tubes showing a parallel arrangement which will be discussed later.

The B_1-horizon containing calcite needles had a skeleton pattern consisting mainly of silt and small fine sand grains. The surfaces of the grains were covered with dense deposits of deep ochracious-colored inorganic colloids. In their density they resembled almost a coating formation. The colloids were entirely soluble in dilute hydrochloric acid. The soil mass could be easily cut with a scalpel without collapsing. By cutting, excellent cross sections of the spaces of the second order could be obtained. The wall bodies were almost entirely dense; the spaces showed sharp edged borders on the cutting planes. The contours of the space cross sections were either irregularly elongated or approached a more or less circular form. Their diameters varied between 300-700μ.

On closer observation it could be seen that the walls of the spaces of the second order were frequently covered with a thin, dark, ochracious-like, brownish glaze. The glaze layer was smooth, shiny, glue- or rosin-like; after ignition it changed to deep red and gained in lustre. It could be observed that the calcite needles were always growing out of this surface

glaze. The needles developed mostly in radiate or druse-like arrangement. Partly, however, they could be found united to asbestos-like wefts.

Particular attention was paid to the micro-determination of pH of the wall surfaces. For this purpose all needles were removed microtechnically, and the residue then taken up with about two parts of boiled distilled water on a cover slip. The micro pH determination was carried out with the Wulff indicator foils. In general a pH of about 6.5 was obtained. In certain spots, where small residues of calcite needles could be observed, a small reaction aureole was noticed on the indicator foil approaching the neutral point or passing it slightly to the alkaline side.

On heating no charring was observed, which indicated that organic colloids were present only to a small extent. The colloids were entirely soluble in dilute hydrochloric acid. By evaporation of the solution on the slide, accumulation of lemon yellow masses could be observed on the margin (colored by $FeCl_3 + 6\ H_2O$) which gradually formed a uniform membrane. By continuous decrease of its water content, the membrane formed numerous wrinkles, and later a network of more or less polygonal cracks. The color turned into brown ($FeCl_3 + 3\ H_2O$), and after strong heating into reddish-brown (Fe_2O_3).

The calcite nature of the needles was recognized by boiling in cobalt solution which resulted in a blue coloration.

Description of needles and locations in chernozem. The needles found in a chernozem near Szeged in Hungary were much finer and longer than those in the brown earth. They had a diameter of only 0.7-0.8μ but obtained a length of 350μ and more. They were stiff, brittle, and straight, never bent or tendril-like. They were never observed growing parallel out of the substrate, as can be noticed in artificial experiments, but always radiate, mostly in well developed druses. (fig. 82). Sometimes they were entangled and combined by partial resolution into irregular accumulations and wefts of an asbestos-like appearance. Where these accumulations reached a higher degree they could be noticed macroscopically in the form of "pseudomycelium." Between and on the needles small deposits of colloid particles of ochracious color was always observed.

The chernozem exhibited a humus horizon to a depth of more than 1 meter. The reaction changed gradually from pH 6.6 in the upper horizon to pH 7.2 in the subsoil. The formation of needles was noticed at a depth of 60-70 cm. In the deeper

layers crystals of lime were found only in the form of flowery precipitations.

The needles were generally found only in the spaces of the second order ranging in diameter from 50μ to 3 mm. The wall surfaces had a scurfy relief but were covered with the shiny layer of humic substances. The interior of the wall bodies was dense and showed the regular intertextic fabric of the chernozem. The delicate films surrounding the mineral grains were dirty ochre in color. On heating a charring of the film was noticed. After ignition the color turned to a yellowish vermillion. The residue treated with potassium ferrocyanide and dilute hydrochloric acid gave a uniform blue stain of Berlin blue. This indicates that the humic substance producing the grain films contained a considerable quantity of iron hydroxide.

The needles were growing mostly on the surface of the space walls. The reaction of some surface parts of the space walls, after a careful removing of the needles, was around pH 6.8. It is very important for the explanation of the needle formation that needles were also noticed developing directly on the surface films of single mineral grains, as pictured in fig. 83. A small glass dish was filled with 40 per cent potassium chloride solution containing 3 per cent dissolved agar. The solution was acidified with hydrochloric acid. The contents of the dish were left to dry out at room temperature. After drying, cubical crystals could be found as well as needles and crystalline efflorescences. Needles were growing in great abundance out of the shrinking agar gel; cubical crystals were found on the bottom of the glass dish near the side walls; crystalline efflorescences were found creeping up the glass walls. The experiment demonstrates the formations in the soil, and every type of precipitation corresponds to a crystal type found in the soil. It may be mentioned that many of the cubical crystals showed re-solution of their summits resulting in shapes similar to the grain-like crystals developed in the soil solution.

The experiment showed that needles are formed growing out of the pores of a colloid gel. The potassium chloride needles obtained were glassy, angular, quadratic in cross section, about 0.5 mm. in diameter and several centimeters in length. They were mostly straight, but partly tendril-like. Every needle had a peculiar base formation resembling a small pedestal.

In order to observe the influence of the natural humus gels on needle formation, a sample of the chernozem of Szeged, mentioned above, was placed in a glass dish with a perforated

bottom. The dish was put in a potassium chloride solution. The salt effloresced in the form of a crystalline crust on the surface, showing rapid evaporation and a high salt concentration. After removing the surface layer, however, the spaces of the second order underneath, as well as the spaces of deeper layers, were found to be filled with fine needles of potassium chloride of almost exactly the same size and shape as the calcium carbonate needles produced in the same soil under natural conditions.

In order to repeat the same experiment with an inorganic colloid gel, iron hydroxide was placed in a similar dish and set in a potassium chloride solution acidified with hydrochloric acid. The iron hydroxide previously had been rendered crumbly by mixing with a small amount of distilled water. In this case the salt needles effloresced even on the surface of the iron hydroxide. They were glassy, quadratic in cross section, and had a diameter of from 8 to 40 mm. The maximum length was about 2 mm. In a large part lateral fusions resulting in ribbon-like formations could be observed. Needles were noted in almost every space of the second order inside the colloid body. Crystalline salt crusts could be seen on the surface; the majority, however, were at the margin of the glass dish.

Experiments by other investigators. The most important experiments on the needle formations of salts were those of K. Schultze. He studied the process of efflorescence under various conditions using solutions of sodium silicate acidified with hydrochloric acid. Some of his fundamental experiments will be mentioned in one of the following paragraphs. With regard to the reaction of the substrate, Schultze could obtain similar types of efflorescences to those to be found in soil. The alkaline silica gel was whitish and dull. Not until after the addition of large amounts of salt could surface efflorescences be obtained in the form of crusty accumulations. The acid gel showed efflorescences of hair-like crystal forms. Similar results also could be obtained with agar gels (17).

The variety of macroscopic efflorescences produced artificially by application of equal amounts of alkali salt solutions to equal volumes of different soils was described by H. Puchner (42). The following details are of particular interest: The presence of colloidal substances in the soil resulted here also in the formation of needle crystals on one hand and flowery precipitations on the other. The influence of the soil reaction could not be recognized because no pH determinations were carried out on these soils. The range of pH could be concluded,

FIG. 65. Porphyropectic fabric. Non-coated mineral grains embedded in a dense ground mass from which they may be removed easily.

FIG. 66. Porphyropeptic fabric. Mineral grains cemented with a dense ground mass. Isolated grains always more or less coated.

FIG. 67. Intertextic fabric. Bare mineral grains united by intergranular braces. In the case of chernozem fabric the grains show transparent humus films.

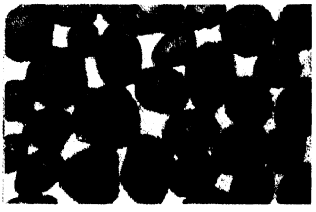


FIG. 68. Chlamydomorphic fabric. Mineral grains surrounded by a uniform colloidal coating. The intergranular spaces are empty.

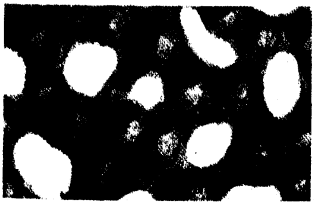


FIG. 69. Plectoamictic fabric. Mineral grains coated and united by intergranular braces.

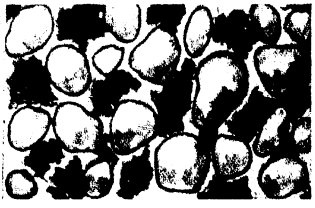


FIG. 70. Agglomeratic fabric. Mineral grains bare. In the intergranular spaces are loose deposits of flocculated or insoluble plasma substances.

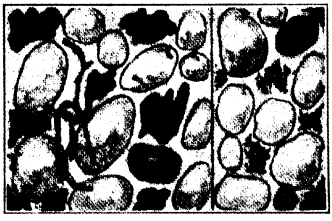


FIG. 71. Bleached sand fabric. Mineral grains bare but occasionally showing residues of coatings or deposits of peptized colloids in the dents and cracks of the grain surface. Right part of the preparation ignited, showing residues of inorganic colloids which were protected from leaching in the pores of the raw humus particles.

FIG. 72. Fragment of a magmoidic soil showing tongue-like marginal contours of the fabric plasma (soil of the "Sablière" near Versailles, France).

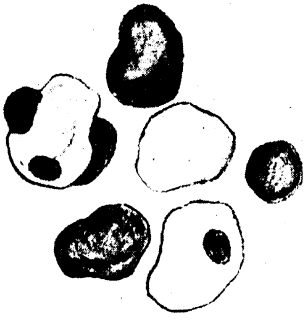


FIG. 73. Debris of the Sablière soil after washing in water.

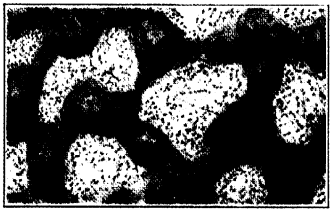


FIG. 74. Mortar fabric. The intergranular spaces are filled with microcrystals of calcite.

FIG. 75. Mammilated aggregate, from black earth near Tower City, North Dakota.

FIG. 76. Wall formation on the surface of an aggregate with a granular shell.

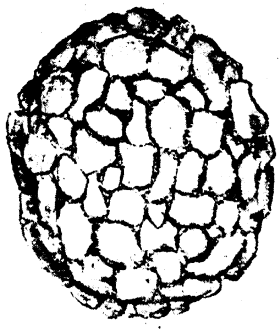


FIG. 77. Artificial granular shell made from quartz grains and chloroform drops.

FIG. 78. Aggregate of a brown earth on limestone, Anninger, Lower Austria.

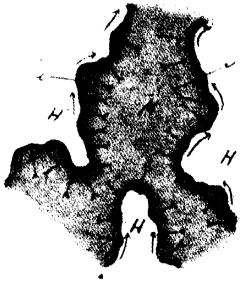


FIG. 79. Pattern of the microdynamic of a steppe soil. (W) wall complex, (H) spaces, (→) centrifugal movement of substances caused by drying, (→) movement of substances caused by leaching, (r) wall crust.

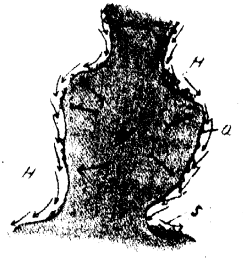


FIG. 80. Pattern of the wall complex of a brown earth. Wall surface erosion by the percolating soil water is predominating. (a) half-denuded mineral grains in the space wall, (s) accumulation of bare mineral grains detached from the wall surface.

FIG. 81. Formation of needle crystals of calcite on the space ceiling of a brown earth on loess near Fernitz, Lower Austria.

FIG. 82. Needles of calcium carbonate in the chernozem near Szeged, Hungary.

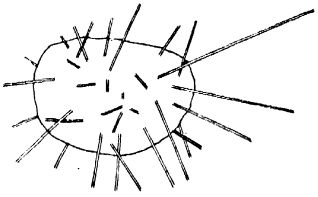


FIG. 83. Quartz grains isolated from the chernozem near Szeged with needles of calcium carbonate developing from the colloid film covering the grain surface.

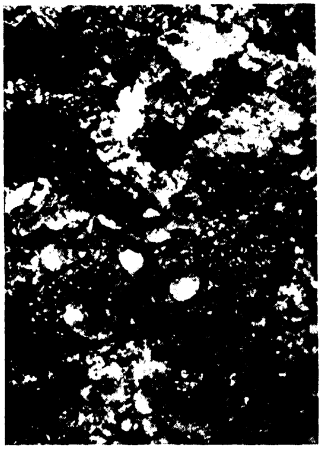
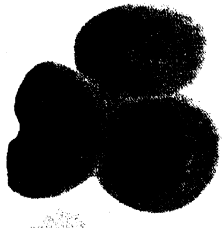


FIG. 85. Lens-shaped crystals of gypsum in muck soil near Mitterndorf, Lower Austria.



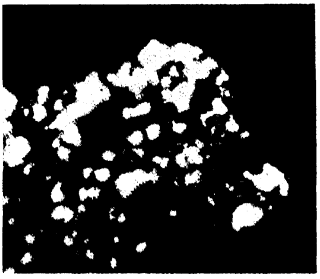


FIG. 84. Hemispherical efflorescences of calcium carbonate in an alluvial soil near Bruck, Lower Austria.

FIG. 86. Pattern of a soil fragment with conducting channel (soil of the Sablière) 20x. (m) colloidal nucleus of conducting channel showing flow structure, (h) lightly ochre-colored marginal part poor in colloids, (o) intense orange-ochre colored ground fabric, (k) old silica almonds originating from previous fabrics of the soil.

FIG. 87. Dough bubbles in the nucleus of the conducting channel which are proof of its previous magmoidic nature (soil of the Sablière) 600x.

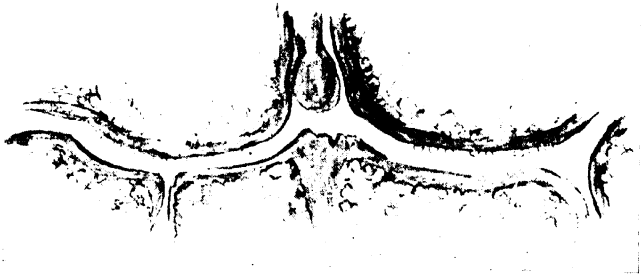


FIG. 88. Horizontal conducting channel (soil of the Sablière).

FIG. 89. Thin section across a fresh worm hole in the A_2-horizon of the soil of the Sablière filled with excretions showing greyish soil material from horizon A_1.

FIG. 90. Worm hole in which the grey material of the excretions has been suspended and deposited to the tube walls by percolating soil water.

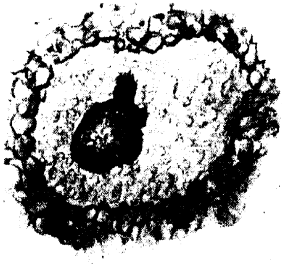


FIG. 91. Intense ochre-colored fresh earthworm excretions in the central opening of greyish deposits from horizon A_1.

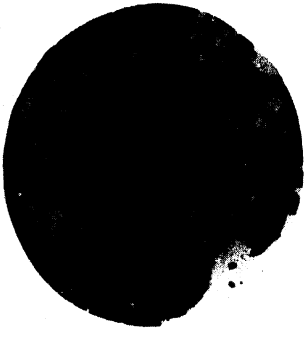


FIG. 92. Thin section of worm hole filled with plasma substances (soil of the Sablière).

FIG. 93. Conducting channel with precipitations of gypsum. Muck soil, Mitterndorf, Lower Austria (subsoil).

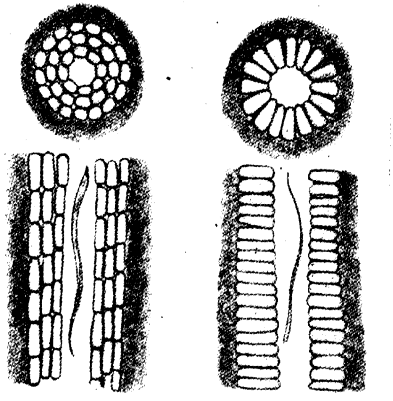


FIG. 94. Longitudinal and cross section through crystal tubes. Left: parallel arrangement. Right: cistern-wall arrangement (20x).

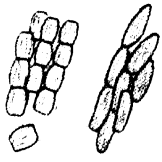


FIG. 95. Barrel-shaped and spindle-shaped calcite crystals. Red earth, Sundance, South Dakota (60x).

FIG. 96. Crystal tube in the subsoil of a brown earth on loess, Fernitz, Lower Austria (35x).

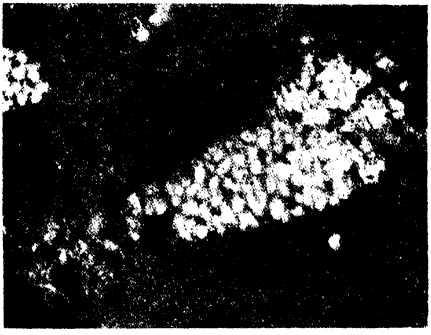


FIG. 97. Crystal chamber of gypsum. Muck soil, Mitterndorf, Lower Austria (35x).

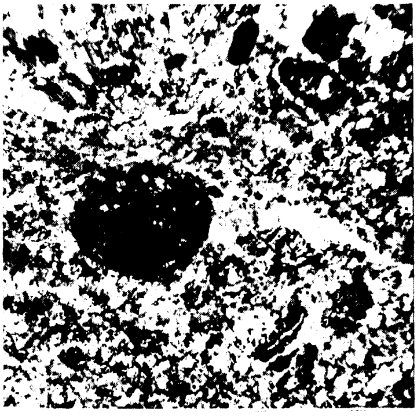


FIG. 98. Thin section of amygdalus. Invasion amygdalus of iron hydroxide, Tama silt loam, A-horizon.

FIG. 99. Intercalary crystals of gypsum (made visible by removal from the embedding soil mass). Ferruginous clay near Vienna (35x).

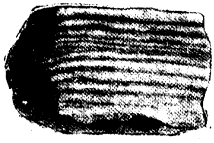


FIG. 100. Soil fragment showing banded fabric.

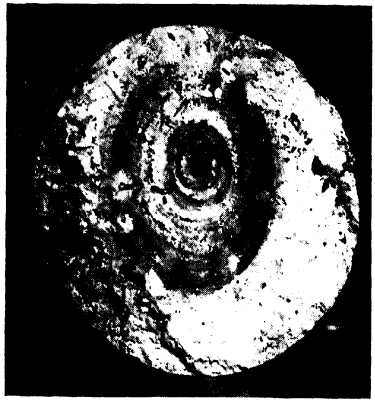


FIG. 101. Soil sample with diffusion rings of iron hydroxide. Tama silt loam near Tama, Iowa (subsoil).

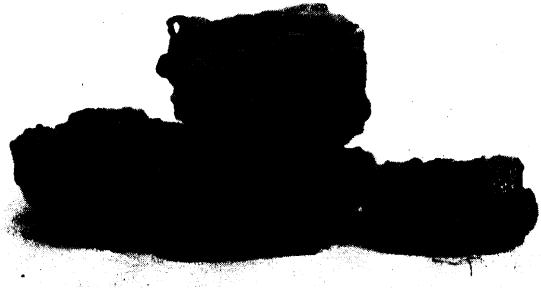


FIG. 102. Fragments of erosion deposits showing laminated fabric. Webster silt loam near Ames, Iowa.

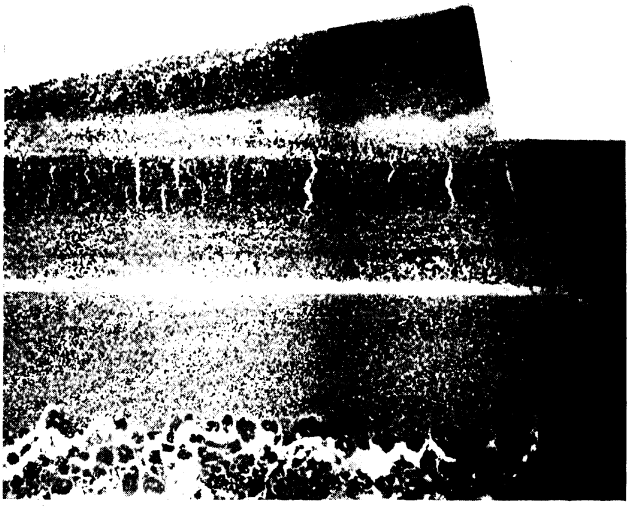


FIG. 103. Thin section of laminated erosion deposits. Webster silt loam near Ames, Iowa.

FIG. 104. Surface of erosion deposits in a cornfield on Webster silt loam near Ames, Iowa.

however, from the general description of the soils ("mergelig-glimmerig," "eisenschüssiger Quarzsand," "Hochmoortorf," etc.). In the majority of cases, the formation of needles seemed to be produced here, as above, in the acid medium; the flowery precipitations were produced in the alkaline. A soil rich in humus showing needle efflorescences was treated with concentrated sulfuric acid. After washing no needles were formed in the soil which were freed from organic substances; only dense crystalline precipitations were produced. Experiments on sands poor in colloids yielded no needle crystals.

Observations of needle formations in soils by other authors. Kuhlmann (1860) found efflorescences of sodium chloride on an iridescent clay in the salt mine of Villefranque. They had the form of sparkling fibers which reached a length of 6 mm. (43).

Doenitz (cited after O. Lehmann) described long needles of ice (30-50 mm. long, 0.4 mm. in diameter) in moist but loose soils after clear winter nights. They appeared below the frozen surface crust which was raised to some extent by their points. Most of the needle tips were sharp. The smaller crystals were not straight but variously bent (43).

K. R. Koch (1877) described needle formation of ice in several soils. The needles reached a length of 6 cm. and a thickness of 0.4-0.5 mm. In most cases they were united in bundles. In the vicinity of the missionary station "Nain" on the coast of Labrador, he found needle crystals of ice in soil down to a depth of 2 to 3 meters. They remained even during the summer season (43).

It may be mentioned that the so-called "pseudomycelium," mainly described by the Russian pedologists in chernozems, can be recognized with the microscope as dense accumulations of needles or thread-shaped crystals of calcium carbonate.

On the theory of needle formations. O. Mügge (44) explained the needle and thread formation by postulating that the salt solution is not only drawn out of the pores by surface evaporation but that it is pressed out by the shrinking colloid body during the process of drying. The crystals thus grow in this manner at their lower ends. Most of the theories of other authors are based on a similar opinion, namely, that the growth of the needles and threads is due mainly to the pressure produced by the drying substrate upon the salt solution present in its pores.

In order to examine this part of the theory K. Schultze (17, 45, 46) introduced long-shaped pieces of acid silica gel vertically

into paraffined beakers. In the bottoms of the beakers were about 20 cc. dilute or concentrated salt solutions (sodium chloride, potassium chloride, ammonium chloride, ammonium bichromate and others). Thus the bases of the gel pieces were standing in the salt solutions. The solutions were covered with a layer of paraffin oil, and the whole system was left to evaporate. After a short time luxuriant growth of crystal threads could be observed only on the upper surfaces of the gel pieces, which parts were most exposed to evaporation. After later addition of ammonium bichromate to the sodium chloride solution the gel was colored upwards in a dark brown color. The growing needles, however, were still white in color. Finally, the growth of both white and reddish-brown threads could be observed.

The experiment of Schultze, especially the penetration of new salts and new water from the lower side into the gel while the crystals were efflorescing on the upper surface, showed that the growth of the needles can continue without the necessity of pressure produced by shrinkage of the gel.

Factors influencing needle formation. In most cases the growth of needles and threads could be observed in acid or neutral soil substrates. Alkaline substrates as a rule produced flowery or crusty efflorescences. It can be assumed that the influence of the reaction is the result of its effect on the capillary system of the surface and of the interior of the porous substrate. With the increase in alkalinity of the soil substrate a higher concentration of the soil solution results, accompanied by the inclination to form interflorescences, i.e., the precipitation of salts in the interior of the drying substrate.

Of great influence on the formation of needle crystals is the degree of evaporation. K. Schultze showed that the more the surfaces of the acid gels were exposed to the motion of air the faster the needles would grow into the air space. The protection of the walls of the experimental dish caused marked differences in the intensity of growth. By artificially reducing the evaporation the formation of efflorescences on the acid silica gels could be prevented. A different behavior could be observed with the alkaline gels. Increased evaporation in a certain stage of the precipitation showed no increase, but rather a cessation of efflorescence formation. The amount of evaporation proved too high in this case, the precipitation of the salt taking place in the interior of the silica gel. By decrease of the evaporation on the surface of the alkaline gels the formation of bundles of crystal threads could be observed. Ribbon-like fusions as well

as bundles of threads could be produced in the last stage of the drying acid gels, particularly with high evaporation and concentrated gels.

POWDERY AND CRUSTY EFFLORESCENCES

The efflorescence of salts in the form of crystalline crusts of powdery precipitations are most common in soils. These indicate usually a concentrated soil solution, alkaline reaction, and a comparatively rapid evaporation rate. Under these conditions the precipitation takes place very rapidly and can be observed microscopically as described on page 153. The crystals produced are very small, 0.5-1.5 μ in diameter, generally rounded, only occasionally showing crystallographic contours. Their appearance and genesis have been described already in the paragraph on mortar fabric.

HEMISPHERICAL EFFLORESCENCES

Description. Accumulations of calcium carbonate of this shape were found mainly on the walls of the larger spaces of an alkaline alluvial soil near Bruck, a. L, Lower Austria. The same formation could be found in some stages of the drying soil on its surface. In the beginning, the accumulations were very regular in shape. The half globular formations were soft, shiny, and about 60 μ in diameter, consisting of a white paste-like mass. They resembled in appearance a young colony of Radiobacter or Azotobacter. Isolated on a slide the soft mass was granular and difficult to smear. It consisted of round-shaped elements of the size of about 1 μ which were rapidly and entirely dissolved with hydrochloric acid. The half-globular accumulations grew continuously as the soil dried, and their shapes gave place to more irregular formations. Finally, compact, knobby crystalline aggregations were formed which reached a diameter of about 150 μ (fig. 84).

The soil showed a fairly dense arrangement of mineral grains, mostly of the size of fine sand, and was low in colloid content.

Genesis. The particular shape of the accumulations is due to the lack of a more or less uniform system of fine capillaries in the surface. The capillaries are wide and irregular in shape and distribution, caused by the low content of colloids. The accumulation generally does not take place right above the center of the opening of a capillary. Since the openings are very irregular in shape the meniscus of liquid in them, seen from above, will not have round-shaped contours. It will have a number

of irregular side branches which will result in an uneven distribution of the substances precipitating out of the evaporating liquid. The accumulation is greatest on the end of those branches which are the narrowest and longest. The precipitation is favored by the higher evaporate rate and the more rapid increase of the salt concentration. Thus the accumulation takes place on particular spots of the surface. The half-globular shape is produced by the surface tension of the semi-liquid accumulations. It can be observed as long as the wall surface is moist. The shape is changed when the surface and a part of the accumulations proceed to dry.

LENS-SHAPED CRYSTALS OF GYPSUM

Description. Gypsum precipitations in the form of lens crystals are found in many soils rich in gypsum, in which, as well as anaerobic conditions in some periods, aerobic conditions also may occur. They were studied mainly in some alkaline muck soils in the southern Viennese Basin, where they were usually found on the walls of empty spaces (fig. 85). As a rule they formed more or less large areas of crystal druses. The soil produced lens crystals as well as grain-shaped crystals which will be described later. Of special significance is the fact that on the surface of accumulations of gypsum grains, which formed a part of the wall surface of an empty space, the formation of lens crystals could be observed. The crystal druses were mostly of such an arrangement that variously-shaped spaces between the single crystals could be noticed. The size of the crystals showed great variety in the different spaces. As well as diameters of 80 μ, others of 500 μ and more could be found. The thickness varied from about 20 to 150 μ. Seen from above the crystals were circular to oval. In some cases a number of concentric lines at the margin of the crystals could be observed, indicating different stages of growth. Single crystallographic planes on the surface of the lenses could not be observed. They had been drawn together to form two concave, more or less strongly vaulted planes which were touching each other in a sharp edge at the margin of the crystal. The crystals were clear and glassy, and could be easily recognized by their optical properties.

Lens crystals of gypsum of similar appearance were found also in a desert gray earth. Macroscopic lens crystals of gypsum found in loose desert soils are well known to the mineralogist. The Museum of Natural History in New York shows a

collection of so-called desert roses, druses of pink lens crystals in rose-like arrangement packed in desert sand or desert clay. In the same collection a druse of large, colorless, glassy lenses of gypsum from Cianciana, Sicily, can be seen; the crystals show a maximum diameter of about 4 inches.

Genesis. In the soil the lens-shaped crystals could be found only on the walls of empty, air filled spaces or in the spaces themselves. Their growth also could be observed in the laboratory on the surface of soil samples taken with a sampling cylinder and kept in a moist state. It can be assumed that the lens crystals originated from a concentrated salt solution adhering to the space wall. Thus they represent not efflorescences but depositions.

2. COMPACT SOIL FABRICS

Compact soil fabrics, as opposed to spongy soil fabrics, show a dense filling of space. This applies, however, only to the spaces of the second order and not to the intergranular spaces which only in particular cases are completely filled with fabric plasma. Spaces in compact soil fabrics also may be produced by plants or animals (root tubes, earthworm tubes, cavities and tubes of mammals) as well as by the formation of cleavage blocks in the drying soil.

The microscopic appearance of compact soils may vary according to the size of the particles prevailing, similar to sedimentary rocks. It can be called psamitic if larger fabric constituents are in preponderance, or pelitic if very small constituents prevail. In the first case the fabric generally is characterized by the presence of intergranular spaces. In the following some types of compact soil fabrics are described in brief.

CHANNEL FABRIC
(Leitbahngefüge)

The movement of concentrated soil solutions in dense soil fabrics depends greatly on the presence of elongated empty spaces. They may be formed by plant roots which are decomposed later, by the activity of earthworms, or they may represent cracks and tears formed by shrinkage.

The soil solution follows the easiest route in its movement, and, therefore, it will move primarily in the empty elongated spaces which we call conducting channels. In the conducting channels of a dried soil horizon we will find deposited all substances which had been dissolved, peptized or suspended in the

soil solution. A microscopic investigation of the contents of the conducting channels, therefore, gives valuable information on the chemistry of the movement of substances in the soil, whereas the fabric of the contents informs us about the mechanism of the movement. We speak of a channel fabric if the ground mass of a soil body showing skeleton and plasma in a definite arrangement is transversed by numerous tubes and veins containing plasma substances. The whole body is divided thus into two phases or fabric units of higher order—a dense non-conducting ground phase and a conducting channel system, resembling somewhat the organization of higher plants and their division into ground parenchyma and vascular tissue.

The contents of the conducting channels can consist of salts (fig. 93) or colloid substances, varying considerably with the soil type and the soil horizon.

Channel fabric is most interesting to study in certain podsols and in degraded yellow earths showing magmoidic fabric. The conducting channels of these soils are filled with colloid substances. The flow structures preserved in them allow not only recognition of the direction of the flow of the former magmoidic mass, but also of the rapidity of movement and of the concentration. The magmoidic nature, however, is expressed most characteristically in the appearance of dough bubbles on the surface of the nuclei of the conducting channels (fig. 87). The parts of the ground fabric of the soil next to the conducting channels are generally lighter in color and contain a lesser amount of colloid substances as indicated in the pattern of fig. 86. This pattern as well as the following figures show arrangements observed in the degraded, yellow-brown soil of the Sablière, near Versailles, France (compare page 151). In the B-horizon of this soil channel fabric with all its connected phenomena was observed to perfection.

Horizontal conducting channels. As well as vertical conducting channels, those which are oriented horizontally or obliquely are also found. Whereas vertical channels containing colloidal substances are frequently entirely filled, horizontal channels largely show depositions limited to the wall surfaces. Sometimes wrinkled or curtain-like formations may be observed. The appearance of a lighter color, and a decrease of plasma substances in the marginal wall parts of the horizontal channels here is less common. In many cases, accumulations of colloidal substances even appear. Lateral efflorescences in the fabric of the wall parts sometimes show well preserved flow structures.

Formation of conducting channels. In the soil of the Sablière, near Versailles, the formation of conducting channels from earthworm tubes could be observed in all stages, since these were preserved in the fabric with great perfection. In fresh tubes which are filled with undestroyed earthworm excretions, it is easily possible to determine in which horizon or part of horizon the animal had taken up soil material and which way it had proceeded through the soil (fig. 89). Material from all horizons, varying greatly in color and appearance, is found deposited. By the percolating soil water after periods of heavy rain the excretions are suspended, and after drying out, deposited on the walls of the tube (fig. 90). Sometimes the empty space in the center has been used by another earthworm; it is filled by other excretions which are most apparent if the material has been brought from another horizon (fig. 91). In the final stage all excretions are washed and removed by the descending soil water; the tube is entirely free from the influx of the concentrated colloidal solutions which are produced in the last stages of the drying soil (fig. 92).

The formation of conducting channels produced by plant roots which decompose and leave an empty tube for the migration of soil solutions could be studied best in a podsol near Hackensack, in northern Minnesota. It was easy to recognize all the details of this type of channel formation by the dense fabric of the B_1-horizon which showed accumulations of large amounts of inorganic and organic colloids. The various specimens showed all the different stages of the decomposition of the plant roots, the formation of soluble and mobile humic substances, the influx of different colloid mixtures, the great morphological variety of the depositions indicating direction and rapidity of flow, the amount of moving substances, and the concentration of the solution.

Channels containing salt deposits. If the soil solution moving in the conducting channels contains large amounts of salts instead of colloids, these will be found as channel deposits in the dried soil. Generally, the tube is entirely filled with salt deposits consisting of small grain-shaped crystals. In the Hackensack podsol the conducting channels in the horizon below B_1 showed an absence of colloids, and were filled with calcium carbonate deposits instead. Figure 93 shows a conducting channel in a muck soil of the southern Viennese Basin filled with precipitations of gypsum.

In the chapter on channel fabric a paragraph on the forma-

tion of crystal tubes should be included, but because of its peculiarity, it will be discussed separately.

FORMATION OF CRYSTAL TUBES
(Kristallröhrenbildung)

By crystal tubes is understood elongated tubes, mostly formed previously by plant roots, which are filled with oriented salt crystals. Up to the present time only crystals of calcite have been found. Crystal tubes have been observed mainly in loess, loess soils (fig. 96), calcareous ground water soils, and red earths rich in lime. Only rarely do the tubes reach a diameter of more than 600μ. The average diameter is 500 μ. As a rule they show a tube-like empty space of about 150-160 μ in the center. In this space, in some cases, residues of the decomposed plant roots may be found. The orientation of the crystals may be in the direction of the longitudinal axis which will be designated as a parallel arrangement, or across the longitudinal axis which will be designated as cistern-wall arrangement.

Parallel arrangement. This arrangement has been found in loess, brown loess loams, and red earths, in the last of which the crystal tubes always occur in deeper horizons and not in the surface layer. The crystal string consists of white, rod-shaped crystals oriented in the direction of the longitudinal axis and arranged in several (usually three) tube-like concentric layers (fig. 94). The greatest velocity of crystal growth takes place in the direction of the least resistance, i. e., in the direction of the longitudinal axis. The development of crystal strings is possible only if the tubes are entirely filled with concentrated soil solution. Contrary to the conditions existing in cistern-wall arrangements, the concentration of the soil solution is produced more uniformly in all parts of the tube, and the formation of all crystals takes place more or less at the same time.

The crystals of the outer layer of the crystal tube are transparent and glassy, those of the inner layer are more or less milky. The empty cylindrical space in the center generally shows on its walls powdery precipitations of calcium carbonate which were produced when the tube became air filled as the soil dried out. The crystals are usually rod-shaped with rounded ends and edges. They show an average length of 150 μ and a diameter of 50 μ. In some cases rhombohedron forms may be noticed. In a deep (probably not recent) red earth on lime-

stone near Sundance, North Dakota, tubes were found which contained barrel-shaped, and in some cases, spindle-shaped crystals. The barrel-shaped crystals reached a length of 50 μ with a like diameter, the spindle-shaped a length of 100 μ with a diameter of about 40 μ (fig. 95).

Cistern-wall arrangement. Crystal tubes which are filled with crystals oriented across the direction of the longitudinal axis of the space (fig. 94) were found particularly in a brown soil of the dry steppe of Horuslar, Rumania (Dobrudsha). They were discribed by Christache V. Oprea (15). The occurrence of the crystal tubes was limited to the surface layer of the soil. It may be assumed that the particular orientation of the crystals is influenced by the fact that the soil is slowly drying out from the surface downward. Thus, the solution in the capillary tubes is gradually concentrated downwards as if in horizontal layers by which the formation of crystal layers takes place one after another. The growth space has the shape of a horizontal disc. The growth of the single crystal in it must have its greatest velocity in a horizontal direction because it is prevented from growing upward by the layer already crystallized and because it meets the zone of highest concentration of the solution in a horizontal direction.

The rod-shaped crystals, also having rounded ends and edges formed by partial re-solution, are about 150μ in length and have an average diameter of 50 μ. The ends next to the empty central space are generally narrower than the ends next to the tube walls.

CRYSTAL CHAMBER FABRIC

By crystal chambers are understood nonconducting spaces of more or less rounded shapes which are generally entirely filled out with grain-like salt crystals. We speak of crystal chamber fabric if the occurrence of crystal chambers in a soil reaches a degree that its fabric is composed by the alternation of two different fabric parts—the ground phase and the crystal chambers.

Up to now, crystal chambers containing only gypsum or calcite grains have been found. Chambers with calcite crystals can be observed in calcareous soil layers showing round-shaped spaces in which an undisturbed and not too rapid crystallization from a bicarbonate solution is possible. Chambers of gypsum are formed under similar conditions from soil solutions rich in gypsum. The most perfect development up to the present was

observed in some muck soils of the southern Viennese Basin in Austria (fig. 97), in which the formation of gypsum is produced by oxidation of iron sulfide.

The formation of crystal chambers takes place by the migration of salts from the ground fabric into the spaces filled with soil solution. The possibility of the precipitation of many large crystals in the more roomy chamber spaces causes the development of a diffusion stream of dissolved salt to the first crystals, already formed. The diffusion stream is produced by the lower concentrated zone around the crystals from which salt has been removed by precipitation. The diffusion stream will last as long as crystals can be precipitated in the space, or as dissolved salts are available in the soil solution infiltrating the ground fabric. Since the velocity of growth is the same in all directions of the space, nut-shaped crystals are formed in the first place. Solutions of lower concentration or even acid soil solutions which penetrate the soil during periods following the time of crystal formation, dissolve a part of the crystals again, thus rounding their points and edges. Frequent changes in concentration are very typical of soil solutions, being caused by the continuous succession of remoistening by more or less heavy rains, and drying in hot and rainless periods.

The diameter of the crystal chambers varies from 100 μ to 1 mm. In some cases, particularly with gypsum chambers, even larger diameters can be observed. The grain crystals show in the case of calcites a diameter of from 50-100 μ, in the case of gypsum from 10-400 μ. As a rule, all grains in a crystal chamber belong to a uniform group of grain sizes. Thus, chambers with uniformly large-sized, as well as those with uniformly small-sized crystals (especially with gypsum) can be found, which indicates that all precipitations within a chamber were formed under identical conditions. Since the size of the grains is influenced mainly by the rapidity of crystallization it is possible to obtain valuable information on the relative rapidity of drying and on the relative concentration of the soil solution by comparison of the grain sizes in different locations and horizons. Gypsum grains are generally colorless and glassy; calcite grains are mostly milky and frequently covered with flowery precipitations. Instead of grain crystals, calcites show well developed rhombohedrons in some cases. In gypsum chambers, grains with partly preserved, crystallographic contours sometimes can be observed. Calcite crystals produced in oblong spaces, especially those which have more or less rectangular

cross sections, show largely prismatic forms which are oriented in the direction of the long axis of the space.

AMYGDALUS FORMATION

In the amygdalus formation, round-shaped spaces are filled with colloidal or crystalline substances. The process is similar to that causing the formation of crystal chambers, and applies not only to salt amygdali (fig. 98), but also to colloid amygdali (fig. 99). If the amygdalus space is not entirely filled with concentrated soil solution, but with air, the growth of the amygdalus can take place by efflorescence. The precipitations are formed first on the space walls and grow gradually toward the center. In this case, the process can be recognized by the presence of different stages of the formation.

Sometimes a partial or complete re-solution of the amygdalus can be observed. Thus, a number of empty amygdalus spaces, in addition to undissolved amygdali, can be noticed. Amygdali in soils are usually present in the form of microscopic formations. Macroscopic amygdali are generally less rounded and irregular in shape, and are known as concretions.

Invasion amygdali and stains. Amygdali not only can be formed in empty spaces, but are even more frequently found in compact ground water soils invading the skeleton pattern. Thin sections of these formations show that the round-shaped and well demarked accumulation does not consist of colloid substances only, but is interspersed by a pattern of mineral grains (fig. 99). It can be assumed that these so-called invasion amygdali were formed in parts of the soil tissue having large intergranular spaces.

Local accumulations which are less compact and definite in shape, and which invade the more or less normal soil tissue, are designated as stain formations in conformity with the general use in pedology.

INTERCALARY FABRIC

Description. The compact soil fabric is interspersed by crystallographically well-developed crystals, generally much larger than the skeleton particles or spaces of the soil. The only intercalary crystals to be found up to the present are those of gypsum.

The fabric was studied in a heavy, partly ferruginous, ground water silty clay of a meadow near Vienna, Austria; the humic surface layer as well as the subsoil was slightly acid in reaction.

The growth of a great number of the intercalary crystals could be noticed in the compact, blue-grayish colored subsoil, which was interspersed with deep brown wrinkles and stains of iron hydroxide. The crystals were present in the form of hemipyramids and prisms, each of which reached a length of about 800μ. They were glassy and showed entirely undestroyed crystal planes, edges and summits, always being found singly and not in the form of druses or accumulations (fig. 99). They were usually entirely embedded in the dense soil mass which showed plectoamictic elementary fabric. Sporadically they could be observed in larger spaces evidently produced by corrosion. As a rule, in these spaces the surfaces of the crystals were covered with deposits of residues of the ground mass.

Genesis. The growth of crystals can overcome considerable resistance as is specifically shown by the splitting effect of salts crystallizing in cracks of rocks. Thus, crystals of considerable size can grow in entirely dense bodies. Since the rapidity of crystallization has a particular influence on the formation of intercalary crystals, the formation of intercalary fabric will be favored in soil parts which dry out very slowly and which contain a comparatively dilute soil solution. These conditions are present in the above mentioned ground water soil near Vienna, having a heavy subsoil. The particular conditions necessary for the formation of intercalary crystals are demonstrated by one of the experiments of K. Schultze with silica gels. Comparatively rapid drying of acid silica gels containing sodium chloride solution resulted only in the formation of needle efflorescences on the surface. When the acid silica gels were allowed to dry out very slowly the salt was precipitated also in the interior in the form of blocks and cubes, the edges of which reached a length of 2 mm. The growth of the crystals produced a number of splits which were extended through the whole gel mass.

BANDED FABRIC

(Bänderumgsgefüge)

Description. In soil masses in which no division into a ground phase and a conducting phase in the form of a system of channels or cracks can be observed, and in which the whole ground fabric is conducting, the movement of the soil solution can be recognized by the formation of banded accumulations of plasma substances in the profile (fig. 100). They indicate different

stages of the level of the soil solution as it retires gradually to deeper soil layers as a result of the drying process. The term "banded fabric" does not refer to the well known large accumulations and oxidation layers of sandy or gravelly ground water soils which are the remnants of former ground water levels which have sunk downwards into deeper horizons. They represent much smaller formations, the details of which can be recognized only microscopically, although the phenomenon as such, in most cases, already may be visible to the naked eye. Outside the soil the phenomenon was described and explained by R. E. Liesegang (Liesegang-rings).

Banded accumulations may extend over the whole width of a profile which thus may be traversed by a great number of horizontally oriented stripes. Microscopically the following arrangement can be seen: Layers rich and poor in plasma substances follow one another in rhythmic succession in a more or less uniform skeleton pattern. The accumulation takes place in the unchanged intergranular spaces which have been filled more or less with colloid substances. Banded fabric thus is much different from laminated fabric in which the differences between the layers is also expressed in changes in regard to the arrangement of the skeletal material.

Genesis. The fundamental details underlying the formation of banded accumulations were adequately described first in the classic experiments of Liesegang (47, 48) on rhythmic precipitations. In the case of banded fabric observed in soils the formation is not produced by chemical precipitation but by a rhythmic repetition of an efflorescence process. Using the interpretation developed by Liesegang as a basis, the formation of the banded accumulations may be explained as a resultant of the following single steps or stages.

1. A soil body with uniform conducting fabric impregnated with a solution containing dissolved or peptized colloids is gradually drying out from the top down.

2. On the upper surface of the wetted soil a part of the substances dissolved or peptized in the solution is precipitated by the evaporation of the solvent or dispersion medium. A capillary draught is produced in the direction of the evaporating surface, by which the dissolved or dispersed substances are transported to the accumulation zone.

3. In the layer of soil immediately below the accumulation zone an eluvial zone poor in dissolved or dispersed substances is formed.

4. By the drying out of the eluvial zone the transport of substances from deeper layers still impregnated with soil solution is interrupted.

5. On the new surface of the soil solution below the dried out eluvial zone a new accumulation zone is formed. The phases 2-5 are repeated as long as the same conditions remain. Generally the banded accumulations gradually become less distinct in the deeper parts of the soil, and the distances between them become greater.

The formation of the accumulations is favored by the fact that the dense accumulation zones are drying out more slowly than the eluvial layers rich in skeleton materials and poor in plasma substances. Thus, the evaporating surface of the soil solution in the accumulation layers persists longer than in the eluvial layers, in consequence of which the zones underneath are most completely divested of liquid and deprived of their plasma substances. In ground water soils where ferrous compounds are accumulated in the bands the precipitation is followed by oxidation which results in a dark brown or reddish coloration of the bands.

Density, thickness and color gradation of the bands. The bands can be very different in their appearance. The distances between the bands, the thickness of the bands and the amount of precipitates accumulated in them (indicated by depth of color) are closely related to (1) the concentration of the soil solution, (2) the density and capillarity of the conducting fabric, (3) the relative amount of soil solution, and (4) the rate of evaporation. A detailed study of all the factors influencing the different development of the bands deserves particular consideration since these factors are of great importance biologically.

Ring-shaped bands. That banded fabric in soils is produced primarily by rhythmic precipitations caused by efflorescence can be demonstrated by following the development of concentric bands frequently found in dried out ground water soils. They can be found encircling the tubes which have been produced mostly by large plant roots. The drying of the neighboring soil parts takes place in concentric layers which are parallel to the different cross sections of the tube wall. The different stages of the receding soil solution are evident by the formation of rhythmic accumulations of colloids intense brown or blackish in color, usually iron and manganese hydroxides.

The development of the onion skin-like crust formations in the interior of certain chernozem aggregates, as described by Christache V. Oprea (see p. 156), seems to be closely related to banded fabric. Here the band formation develops in the opposite direction, the outside ring being formed first, and the drying of the impregnated fabric is not produced from a space situated in the center of the formation but acts concentrically upon a round-shaped body from the outside.

Diffusion rings (Diffusionsringe). Ring formations also can be produced by diffusion. In this case in the cross section of the formation in the first stage an empty hole in the center of a dark-colored disk produced by dense accumulations of plasma substances is seen. If the soil is remoistened, the plasma substances are dissolved, dispersed or suspended again and diffuse deeper into the soil mass. Thus, the former dark-colored circular plane in the cross section will be replaced by a light-colored plane surrounded by a band of accumulated plasma substances more or less concentric to the open space in the center. Sometimes two or three bands can be observed. The inner rings, however, are generally much thinner and lighter in color.

Diffusion rings could be observed developing perfectly in the subsoil of a Tama silt loam half a mile east of Tama, Iowa. The cylindrical accumulations around the conducting grooves, showing a circular plane in the cross section, had a diameter of 0.15 to 5 and more millimeters. In some cases the accumulations extended into the wall to a depth of 4 and more millimeters, thus forming a dark-colored ring of a thickness of 1-2 mm. Occasionally, a considerable number of rings could be observed (fig. 102). The precipitations in both the ring-shaped and the disc-shaped accumulations were densest in the outer margin which indicates that the movement of the dispersed substances took place centrifugally. By microscopic examinations of the outer margin of the bands or circles the direction of the movement can be seen. It is shown by tongue-like projections produced by the flow of concentrated colloid dispersion at parts where wider intergranular spaces allow an easier penetration. In the tongue-like projections colloidal substances are the densest accumulations. All these details show that the ring-shaped accumulations are not formed by efflorescence but by diffusion and deposition. The diffusion rings in the Tama soil were brownish or blackish in color and consisted mainly of iron hydroxide or manganese hydroxide (13).

LAMINATED FABRIC

Erodible soils show, in many cases, that the undisturbed surface soil in relief depressions consists of a great number of layers which differ from each other in the grain sizes of the skeleton material, in the shape, nature, and size of the humus particles, and in the presence of binding substances. An arrangement of this kind showing not only differences in the amount of accumulations of plasma substances, but also complete difference in size, nature and arrangement of all constituents is designated as laminated fabric.

By erosion and sedimentation of transported soil masses an extensive sorting of constituents may be produced according to differences in size, shape, specific weight and solubility. This sorting deposition takes place not only vertically (figs. 102 and 103) but also horizontally (fig. 104).

Differences in the layers of laminated fabrics are produced not only by deposition in flowing or stagnant water, but a great influence is also exerted on layers exposed to the surface through the action of rainfall resulting in a liberation of the skeleton particles from the plasma substances. Also, wind deposits may alternate with water deposits. Substances soluble in water will be deposited in the form of efflorescences. They can migrate through different layers and are precipitated in the form of horizontal bands indicating the different positions of the surface of the soil solution in the drying soil.

The thickness of the strata varies considerably. The most frequent diameters observed range between 0.3 to 1.5 mm. In layers produced by flowing water the direction of the flow can be recognized by the orientation of rod-shaped particles, especially humus splinters and root and stem residues of higher plants. They are largely oriented with their long axis parallel to the direction of the movement.

The study of stratified erosion deposits is highly important in the understanding of the mechanism of erosion since they are able to give valuable information on the role of the different constituents in the erosion process. Bands of highly peptized colloid accumulations indicate binding substances which can be dispersed by the water. Substances absent in the deposits which can be found in parts of the same soil unaffected by erosion indicate components of the binding complex which are entirely removed from the soil fabric because of their high

solubility. In soil aggregates which are deposited in a more or less unaltered state, binding substances stable as to solubility in water and mechanical influences may be recognized. The resistance of binding substances against mechanical influences can be studied advantageously in deposits of windblown soil masses. Detailed communications on the application of microscopic fabric analysis to soil erosion studies will be given in a special publication by the author and his collaborators in Ames.

WRINKLE MARKS

Description. Wrinkle marks represent very irregular banded accumulations in which the parallelism and uniform development of the bands is much disturbed. The stripes are interrupted by large parts in which accumulations are entirely absent. In many cases only some few short lines are left at great distances from one another. The shapes can be so irregular that the band nature is barely visible. Mostly the formation of short wavy lines is predominant, reminiscent of wrinkles or frowns on the face. The wrinkle designs almost always show horizontal orientation. They vary very much in thickness, showing all intermediate formations from short wavy stripes with pointed ends to irregular stainings. Like the bands, they are revealed microscopically as accumulations of plasma substances in the intergranular spaces of undisturbed pre-existant skeleton patterns.

Wrinkle marks usually are found in some dried out ground water soils. They represent accumulations of peptized inorganic colloids in which iron hydroxide or manganese hydroxide prevails. They are brownish, reddish or blackish in color on a grey or bluish-grey ground mass.

Genesis. Wrinkle marks are produced by a process similar to that in the case of banded fabric. Banded accumulations are possible only if the fabric represents a more or less uniform capillary system and if the soil solution is more or less uniform in concentration. These conditions, however, occur only rarely in soils. Irregularities may cause such great disturbances in band formation that only the horizontal orientation of the wrinkle marks scattered all over the profile and the microscopic arrangement of the accumulations remain out of the characteristics of ribbon formation. Wrinkle marks may be caused by efflorescences produced on different surfaces of the receding

soil solution. The disturbances are of great importance in fabric analysis, since they aid in the reconstruction of the previous movements of the soil solution in detail. All changes of shape and course are produced in exact response to conditions in the soil. They are dictated by the capillary system of the different microscopic locations, the changes in concentration of the soil solution, by the degree of evaporation and by influences of chemical or chemo-physical nature.

Part IV
BIOLOGICAL SOIL MICROSCOPY

INTRODUCTION

This chapter deals with microscopic soil biology, by which is understood a study of living things in the soil and their activity in the microscopic dimensions as perceived by direct observation. The subject and unit of observation is the microhabitat together with its conditions, the association of organisms found in it, as well as the particular morphology and activity of the organisms as influenced by its conditions. In the program of microscopic soil biology is included not only the observation of the life of microorganisms in different microhabitats, but also the microscopic study of the life of parts of higher plants, such as plant rootlets.

CHAPTER I

Characteristics of the Microhabitat

Microscopic observations show that the microhabitats represent independent biological units except for the interrelations which exist between the different microhabitats of a soil and makes each area part of the same biological system. Every soil shows a number of different habitat types characterized by the particular associations of organisms found in them. Association, activity and morphology of the organisms is influenced primarily by the space conditions, the microclimate, the pH and salt concentrations and the food conditions in the microhabitat.

1. SPACE SIZE

The influence of the space size is two-fold. Some organisms are limited in occurrence to the larger spaces because they are too large to develop in small spaces, others because of changes in general biological conditions which vary with spaces of different sizes in the same soil. The latter refers primarily to different air conditions but also, in correlation with them, to the changes in pH and salt concentration.

The limiting effect of size can be observed chiefly with fruiting bodies of fungi. In experiments with Sassafrass sandy loam the author, together with C. E. Renn, found that fruiting bodies of *Cunninghamella* occurred only in spaces with a diameter greater than 600 μ. Likewise, conidiophores of *Botrytis* and sporangia of *Mucor* and *Rhizopus* were always found only in spaces sufficiently large for their complete development. In a dried out Austrian muck soil interesting changes in the growth of sporangiophores of *Rhizopus nodosus* were noticed. In spaces too small for the normal development of those sporangiophores, which generally are more than 900 μ high and bear sporangia of 100 μ or more in diameter, the fungus developed stems which were variously bent according to the shape of the spaces, in some cases being almost spirally curled (fig. 106). This observation was not made with other *Rhizopus* or *Mucor* varieties. Mycelium of a species of *Humicola* was found either on the soil surface or in large spaces in the interior of the soil; it was al-

most entirely absent in small spaces (5). Large protozoa occur only in small pools (either macroscopic or microscopic) on the soil surface, or in soils with large spaces. The occurrence of dwarfed forms of protozoa in many soils may be due to the restricting effect of the small soil spaces. The occurrence of large protozoa in empty root channels or spaces produced by the decomposition of plant and animal residues, which can primarily be observed by the accumulation of cysts, is partly due to the favorable food conditions and partly to the presence of sufficient space for their activity.

Some large organisms may be found growing in smaller spaces or even compact soil parts. Thus oogonia of *Achlya gracilipes* may be found entirely embedded in compact soil material. The roots of higher plants generally favor the spaces of the second order in spongy soils; they also are able, however, to penetrate through compact soil parts forming a new system of channels which play an important role in the biology and dynamics of certain soils.

A luxurious development of fungi is observed generally in spaces of the second and higher orders, but in spaces of the first order in spongy soils such growth is either lacking or greatly suppressed. On the other hand, the growth of certain bacteria is stimulated on plant and animal residues entirely embedded in soil materials, provided suitable moisture conditions exist.

2. MICROCLIMATIC CONDITIONS

The climate of a habitat is determined by its conditions with regard to temperature, moisture, air pressure, insolation and air movement. About two decades ago the observation of climatic conditions was more or less confined to the weather stations. Their observations applied to large land areas and may be designated in their totality as the regional climate (Grossklima). Remarkable differences, however, are found also in the climates of different neighboring localities. Special attention to the particular climate of certain places was given by the plant ecologist after the appearance of the book of Gregor Kraus, "Boden und Klima auf kleinstem Raum" (1911). In this book the necessity of the observations of the soil climate was particularly emphasized. Kraus found a locality in central Germany where the temperature of the soil (bare of vegetation) showed a summer maximum which was 28°C. higher than the maximal air temperature. The fact that

these local conditions have an important influence on the soil formation was particularly recognized by pedologists in countries which show great variation in topography and plant cover The climatic conditions of this kind may be designated as the local climate.

Direct microscopic investigations of soils show that considerable differences, especially in moisture and air conditions as well as in air pressure and air motion, exist in the microscopic dimensions. They have a remarkable influence on soil formation, particularly in forming microscopic illuvial zones in a way similar to the accumulation of salts and colloids on the surface of large soil areas under the influence of the regional or local climate. The significance of microclimate to the ecology of microorganisms is shown by the close relationships existing between climatic conditions and life in microscopic dimensions.

In view of the author's investigations on the microhabitat of soil organisms, A. Janke proposed the term "microclimate" for climate conditions in microscopic localities (Arch. f. Mikrobiol. Bd. 5, 1934, 224). Most of the microclimatic factors are effective in dimensions too small to be measured by instruments. Their agency is recognized, however, by their influence on the development of the microorganisms and the migration of salts and peptizable colloids.

The most sensitive indicators of different microclimatic conditions are salt efflorescences. Their occurrence in soil spaces always denotes well aerated habitats. Their distribution on the surface relief of the space walls is not accidental. Two stalagmitic relief parts on the soil surface, each of about the same size and shape and having the same capillary system in its interior, but one situated at the top of an elevation and the other at the bottom of a depression, will show great differences in behavior with regard to efflorescence. The first, at the top, will develop great amounts of rapidly growing efflorescences, the other, in the depression, might show no efflorescences at all. This difference in behavior is produced by the difference in degree of aeration and in a better replacement of the saturated air by air less saturated. Thus, one of the principal microclimatic factors in air filled soil spaces is "wind" movement of air. The relationship between air motion and efflorescence has been studied repeatedly in laboratory experiments and by laboratory observation; a number of these are reported in K. Schultze's book on efflorescences (17). A small glass dish with high vertical walls filled nearly to the top with a salt solution will show the

formation of creeping efflorescences on the internal sides of the glass walls. If only a small amount of the salt solution is poured into the dish so that its surface is close to the bottom, the crystallization will be observed in the center of the surface of the liquid rather than on the marginal parts which are protected against the air movement by the glass walls. The experiment shows that it is not necessary that evaporation is stopped completely in certain parts. Different rates of evaporation are sufficient to effect greatly the processes of efflorescence.

The great difference in the growth of microorganisms on the surface of the soil as compared to that in the interior habitats is due primarily to a change of the climatic conditions and, secondly, to differences in space restrictions and in food conditions. In addition to moisture, temperature and aeration, another important factor is operative on the surface; namely, the light factor which brings about the development of characteristic species of green and blue algae, diatoms and microscopic mosses. With regard to the fungus flora, many species have been observed which grow abundantly on the soil surface but are much suppressed or entirely absent in the interior of the soil.

The complete change of the microflora caused by different moisture and air conditions has been specifically shown by the investigations of A. Brunner-Stonawski on a drainage experimental field in Petzenkirchen, Lower Austria. The undrained parts of the field showed an almost complete absence of fungi and a remarkable development of bacteria and diatoms. Artificial draining of soil parts taken under undisturbed conditions cause the disappearance of the bacteria and diatoms found in the wet soil and the luxurious development of fungi, especially *Verticillium, Hyalopus, Oedocephallum, Mortierella, Glio-cladium* and *Alternaria.* The fungus flora was, in most cases, the same as found in the field on naturally drained parts of the experimental plot. From these investigations it was concluded that it is possible to recognize the effect of drainage by the composition and development of the microflora in that it is so sensitive with regard to moisture conditions.

3. REACTION AND SALT CONCENTRATION

A great variation of the pH in microscopic dimensions is a characteristic of a number of soils. The author found that differences in reaction measured microscopically ranged from pH 6.3 to pH 8.4 in a soil which showed a pH of 7.5 by the cenven-

tional macromethod (3). The pH in microscopic dimensions is particularly influenced by accumulations of salts (efflorescences in space walls) or by lime or fertilizer particles. Great changes also may be produced by the activity of filamentous fungi.

F. Sekera measured the change of pH in the root hair zones with a micro-quinhydrone electrode (35). The pattern in fig. 107 shows the end of a plant root in a soil with a more or less even pH of about 6.0. The carbon dioxide evolution in the zone of the root hairs causes a change to pH 4.9-5.8. Sekera draws the conclusion from his observations that the plant roots always live in a medium which is lower in pH than usually is determined. Since the development of the plant depends on the reaction of the root zone, and since the change in pH brought about by the root hairs is different in different soils, the pH figures as quantitative values do not have the physiological importance once attached to them. There are close relationships between the change of reaction in the root zone and the buffer capacity of the soil.

It is often observed microscopically that certain microorganisms cease to develop on places where efflorescences of salts are beginning to be precipitated. The phenomenon is evidently caused not only by the change of pH, but also because the concentration of the soil solution in this place became higher than the value corresponding to the maximal suction force of the microorganism. In some cases, morphological degeneration of fungi in microhabitats with high salt concentrations has been observed by the author. The degeneration of sporangiophores of *Rhizopus nodosus* has been noticed especially in an Austrian muck soil. With increasing precipitation of salts the fungus ceased to grow and retreated gradually into spaces deeper in the soil (5).

4. FOOD CONDITIONS

The soil represents not a single culture medium, but consists of a number of different media, each characterized by its own association of organisms which generally do not occur on other substrates of the soil. At the same time, the association of organisms on a given medium is influenced by such previously mentioned factors as the microclimatic conditions, the pH, the salt concentration, the space size and others.

The principal media observed microscopically as influencing the association of organisms in the microhabitats of the natural soil are: the soil solution, including the dissolved or suspend-

ed organic substances; humic substances; fresh plant residues; lignified stem and root residues; fungus filaments; nitrogenous residues; and living microorganisms.

The soil solution. A number of microorganisms are found in places where no organic residues are noticeable microscopically. Observations in soil culture dishes, in which the same organisms are found growing from or in isolated drops of soil solution on the dish walls, show that these organisms are living on substances dissolved or suspended in the soil solution. Suspended microbial fragments, barely visible by direct microscopic investigations in soils, are recognized by buried slides prepared according to the Rossi-Cholodny technique. The presence of dissolved organic substances is often made visible by charring (see page 78). The substances may accumulate at evaporating surfaces (space walls, soil surface) and may there result in an increased growth of certain organisms. This was shown by an experiment with gum arabic in Sassafrass sandy loam in soil culture dishes. The parts of the densest accumulation of precipitated gum arabic showed the densest growth of *Penicillia* (8).

The soil solution is the favored habitat of a number of soil bacteria. Also, a number of fungus species are found at locations where, in addition to those dissolved or suspended in the solution, no other organic substances are present. Typical representatives of the group are the different species of *Hyalopus* which very frequently are found fruiting in spaces of well moistened soils, and which soon disappear when the soil proceeds to dry (figs. 108 and 109). Another typical fungus frequently found in podsolic soils is *Verticillium chlamydosporium* Goddard (fig. 110). Repeatedly found in entirely mineral soil parts infiltrated with soil solution were species of *Sporotrichum, Cladosporium, Mycogone* and certain actinomyces. The fungi and actinomyces appear only in microhabitats with sufficient aeration.

Several examples showing how much the soil solution as a culture medium is influenced by diffusable organic substances brought into the soil by additions, or produced by the decomposition of additions, will be presented in the following paragraphs.

Flaky humic substances. Certain fungi, especially species of *Mucor* and *Rhizopus,* occur in soil parts in which a great amount of blackish flaky humic substances are observed. It could not be determined whether the development of the fungus species

was due to the humic substances or to suspended organisms in the soil solution, or to the latter itself, with which the humic soil parts were impregnated. The fungus species, however, are rarely found in mineral soils or location impregnated with soil solution; neither are they typical for plant roots and other plant residues. They often are found, however, on nitrogenous plant residues and on remnants of soil animals.

Fresh plant residues. The difference of the flora of fresh plant residues from half-decomposed, fibrous plant residues is particularly noticeable by direct microscopic observations in well aerated microhabitats. The decomposition in these habitats takes place primarily by fungi which soon overgrow the bacteria. On the fresh residues including plant roots in the first stage of decomposition, species of *Aspergillus, Penicillium, Gliocladium* and *Verticillium* are most commonly found. Among the first group *Aspergillus niger* and *Penicillium lilacinum* can be considered as typical soil fungi found on fresh plant residues.

Under anaerobic conditions rapid bacterial decomposition almost entirely replaces fungal decomposition, as can be seen readily in preparations of macerated plant residues isolated from the soil. Along with the bacteria is noticed an increase of the protozoa which can be observed directly, as well as by the accumulation of protozoan cysts, on the residues in dried out soils. In addition to protozoa, other animals may also be found, especially nematodes. Mites and collembolas are found only in the air filled space systems of spongy soils. Their occurrence often is greatly increased in the close vicinity of fresh plant residues.

Lignified stem and root residues. In aerated microhabitats, partly decomposed stem and root residues from which the easily decomposable substances, including a part of the cellulose, have been taken out, have a flora distinctly different from that of fresh materials. Further decomposition seems to take place only through the activity of some slowly growing fungi, such as species of *Alternaria* (very frequently), *Acrothecium* (fig. 111), *Acladium, Cladosporium* and *Trichothecium.*

Nitrogenous organic residues. Some soils are rich in remnants of small soil insects. In aerated habitats they always are attacked at first by actinomyces, while fungi, though their growth is greatly increased in the vicinity of the residues, attack the remnants directly only in later stages of the decomposition. This fungus flora consists primarily of species of *Mucor, Rhizopus* and *Fusarium.*

Figure 112 shows a typical accumulation of fungus mycelium and bodies around insect remnants, which fills up the soil space almost entirely. If the accumulation of mycelium is isolated on a slide and dissected, the interior always shows the resistant chitin remnants of the animal covered with mycelium and spirals of actinomyces. The development of spirals of actinomyces without the succession of *Mucor* is shown in fig. 113; a drawing of an isolated spiral from the same microhabitat is given in fig. 114.

A similar succession is produced by the addition of pure protein particles to the soil (8). Figure 115 shows a zein particle introduced to Sassafras sandy loam attacked by an actinomyces of the chromogenous group. In fig. 116 another zein particle is seen attacked by the same organism showing a later stage, in which the particle is entirely encased by the filaments of the actinomyces. Instead of the protein particles, the formation of chalky-white cottony balls is observed. In fig. 117 the decomposition is much advanced. The zein particle has shrunk together and filaments of another organism, which appeared from the conidiophores to be a *Gliocladium,* are approaching. The marked antagonism between the actinomyces and the fungus is clearly seen from the presence of a free space between them. This space is clearly visible in the picture above the zein particle, but is covered below somewhat because of the concentrical arrangement of the *Gliocladium* around the protein particle. Not until the decomposition of the protein particle has proceeded to a certain degree, and not until the actinomyces is getting weaker in its vitality does the *Gliocladium* advance and take possession of the zein particle or of what is left of it.

Extremely rapid decomposition of zein particles by a rosewood-colored species of actinomyces is seen in fig. 118 where the protein appears half digested, the particle having shrunk to half of its original size. Fig. 119 shows the final stage which is established after two or three days, and in which nothing but the empty space is left. The bottom of the empty cavity was found covered with filaments of the actinomyces, but no residue was observed. If a residue had formed it must have dissolved and diffused into the neighboring soil parts.

From fig. 117 it could be seen that the *Gliocladium* was able to grow at some distance from the protein particle. It has been observed that additions of high protein materials have a great influence on the soil solution, even in cases where the protein (like zein) is insoluble in water. The influence is evidenced

throughout the soil by a striking increase in the development and activity of the microflora and microfauna, and by the appearance of new species. Among the fungi, species of *Cunninghamella* seem to be organisms which grow typically in habitats free from visible residues rich in protein, but which are developing as a result of protein additions to the soil (8). The decomposition of animal residues by short bacterial rods and spore formers under good moisture conditions often can be seen from buried slides following the Rossi-Cholodny method. Under high moisture conditions, growth of a *Saprolegnia (Achlya gracilipes)* was found on insect residues (fig. 120).

Living organisms. The appearance of numerous organisms is followed mostly by others which feed on them. Thus, a luxuriant development of bacteria in sufficiently large spaces filled with water is always followed by that of protozoa, that of fungi by mites and nematodes, etc.

Cases in which fungi are found living as parasites on other fungi seem to be quite frequent in soils. The author made a special study of fungus parasitism using *Mucor glomerula* which was found living on *Rhizopus nodosus* (fig. 121). In some cases sporangiophores of the *Mucor* were found growing from sporangiophores of the *Rhizopus*, the arrangement of the sporangia of both resembling a sporangiophore of *Thamnidium* (fig. 122). The parasitism also could be established and studied outside the soil in artificial cultures (5).

Apart from parasitism, direct microscopic methods are suitable especially for the study of symbiotic relationships within communities, such as that existing between the mycorrhiza and the roots of higher plants.

CHAPTER II

Soil Fabrics and Soil Biology

1. SALT AND COLLOID PRECIPITATIONS AS INDICATORS OF BIOLOGICAL CONDITIONS

Salt efflorescences. The formation of efflorescences in the interior of the soil is always restricted to air filled spaces. Thus, they are indicators of aerobic conditions provided that no other forms of salt or colloid precipitations are found. This point is of importance because every soil may form efflorescences in the last stages of the drying process. The moisture and air conditions also may be reconstructed from the arrangement of the efflorescences in the interior of the soil.

Needle-shaped crystals of calcite indicate a slightly acid to neutral soil solution of low concentration, especially in the case when thin, long and scattered needles are observed. The denser the arrangement of the needles, and the more ribbon-like the fusions of crystals, the higher was the concentration of the soil solution. Needle crystals indicate that peptized organic or inorganic colloids which greatly favor the formation of needles are contained in the fabric plasma.

Powdery efflorescences indicate a highly concentrated and alkaline soil solution especially when, in addition to them, interflorescences are observed. The degree af alkalinity will be shown by the kind of salts occurring in the efflorescences. A high alkalinity is accompanied by a prevalence of alkali salts. The degree of the evaporation and of the concentration of the soil solution may be seen from the size of the precipitated crystals.

Crystal chambers, crystal tubes. In contrast to efflorescences, crystal chambers and crystal tubes indicate the prevalence of strictly anaerobic conditions. A continuous change from anaerobic to aerobic conditions and *vice versa* may be indicated by the formation of crystal chambers as well as of newly formed empty spaces with efflorescences or deposition crystals (gypsum lenses) on their walls. Strictly anaerobic conditions also are marked by the formation of large intercalary crystals.

FIG. 105. Soil fragment showing wrinkle marks.

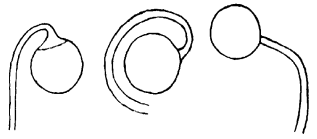


FIG. 106. Sporangiophores of *Rhizopus nodosus* with coiled stems.

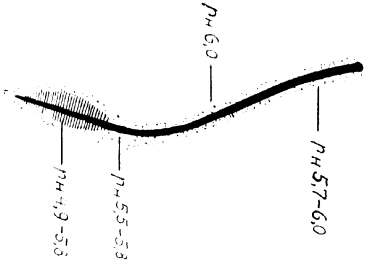


FIG. 107. Change of pH in the zone of the root hairs (from Sekera).

FIG. 108. *Hyalopus crystallinus* in soil from the Beskyd Mountains, Czechoslovakia (72x).

FIG. 109. *Hyalopus crystallinus* transferred to soil extract mannitol agar (108x).

FIG. 110. *Verticillium chlamydosporium* Goddard in Sassafras sandy loam, New Brunswick, N. J. (35x).

FIG. 111. *Acrothecium* sp. on half-decomposed plant root in Sassafras sandy loam (400x).

FIG. 112. Accumulation of mycelium and fruiting bodies of *Mucor alternans* around insect remnants (72x).

FIG. 113. Spirals of *Actinomyces* sp. on fragments of insect residues (72x).

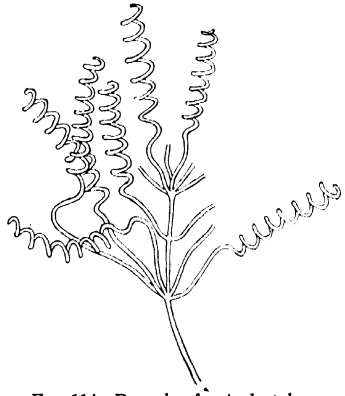


FIG. 114. Branch of spirals taken from *Actinomyces* in figure 113.

FIG. 115. Zein particle attacked by two colonies of *Actinomyces*.

FIG. 116. Zein particle entirely encased in mycelium of *Actinomyces*.

FIG. 117. (left) Decayed zein particle surrounded by *Gliocladium* sp.

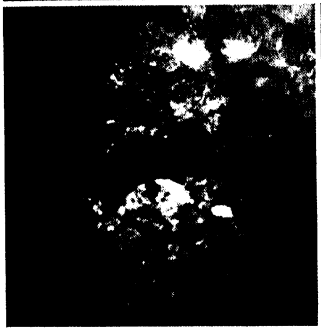


FIG. 118. Zein particle encased and half digested by an *Actinomyces*.

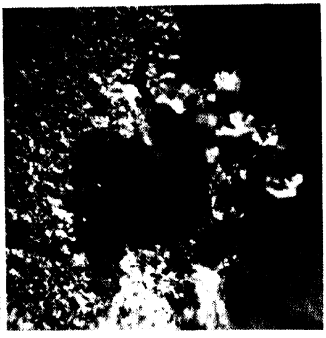


FIG. 119. Zein particle almost entirely digested by the *Actinomyces*, leaving a round empty space.

FIG. 120. *Achlya gracilipes* in the shore soil of a pond near Wald, Styria (35x).

FIG. 121. *Mucor glomerula* (right) as a parasite in mycelium of *Rhizopus nodosus* in muck soil near Mitterndorf, Lower Austria. Sporangiophores of *Rhizopus* are seen at the right and at the upper left (35x).

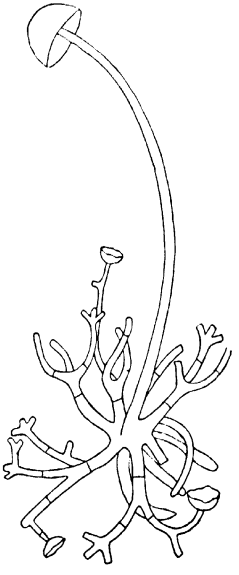


FIG. 122. *Mucor glomerula* developed on sporangiophore of *Rhizopus nodosus*.

FIG. 123. Thin section of salt soil, Apetlon in Burgenland, Austria. The preparation shows accumulations of an alkali-soluble humic substance (dark spots with shrinkage cracks and precipitations of salts; light parts with embedded mineral grains).

FIG. 124. Youth stage of *Gliocladium* showing Hyalopus-like fruiting bodies. The fungus is growing on fresh plant residues. (Drawing by Martha V. Samassa.)

FIG. 125. *Mucor glomerula* in alluvial soil near Bruck, Lower Austria (35x).

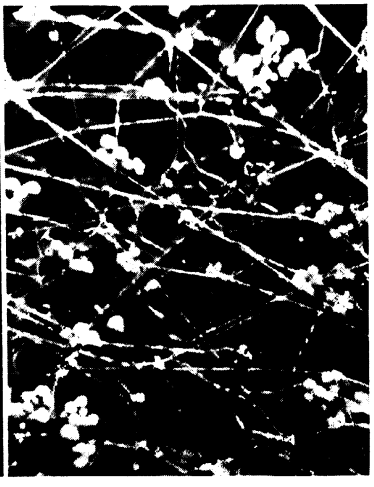


FIG. 126. The *Mucor glomerula* of figure 125 transferred to alkaline soil-extract mannitol agar (35x).

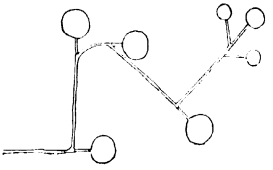


FIG. 127. Habit of *Mucor glomerula* on acid Wöltje-agar.

FIG. 128. (above) Fruiting bodies of Cladosporium in soil of the Beskyd Mountains, Czechoslovakia (108x).

FIG. 129. (right) Preparation of a drop of capillary water isolated from soil. Organisms stained by the Gram's method.

FIG. 130. (above) Protozoa retiring to side channels of the spaces with decreasing water content of the soil.

FIG. 131. Protozoon at water meniscus.

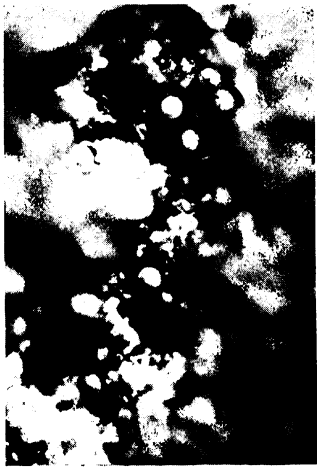


FIG. 132. Protozoan cysts in forest brown earth, Westchester, Maryland.

Amygdali, banded fabric. Anaerobic conditions are recognized also in soil parts containing amygdalus formations which are particularly frequent in the form of invasion amygdali. Changes from anaerobic to aerobic conditions are shown by banded fabric. While banded fabric indicates more or less uniform conditions a great variety of different conditions is marked by wrinkle formations which are sensitive indicators of changes in aeration and in the concentration of the soil solution.

2. SOIL FABRICS AND PLANT GROWTH

"Crumb structure," "Single grain structure." Naturally developed soils are in the majority of cases coherent. Loose soils which are open to excessive water and wind erosion are comparatively rare. Thus, soils with "crumb structure" usually show a spongy fabric microscopically and only in some cases consist of loose aggregates. Agricultural soils, the fabric of which is repeatedly destroyed by tillage, soon redevelop their former coherent nature, which may show either a variety of different compact types or spongy fabric types.

The formation of "crumb structure" is generally explained as originating by a flocculation process produced by the effect of electrolytes on the absorbing complex of the soil. This conception is expressed by the well known ball patterns commonly used in text books on soil science. Microscopic investigations show that the particular morphology of aggregates and wall complexes of soils rarely can be explained by this scheme of formation. It was shown in a previous chapter that the interior fabric of the aggregates of the true chernozems is mostly compact and that the complexes show, in many cases, such a coherence that they are split open by needles under the microscope only with considerable pressure. Flaky comlexes are found for the most part in some deposits of windblown soils, the morphology of which is produced by other processes.

According to the conception of the author, the formation of a stable crumb structure is possible in a soil if it contains binding substances which are sufficiently stable to prevent a complete separation of the soil into its single constituents by the action of water. The binding is due to molecular coherence rather than to electrical flocculation. The formation of the grain complexes (aggregates, wall bodies, etc.) in agricultural soil is promoted by tillage; in naturally developed spongy soils, primarily by the corrosive action of the percolating soil water, and in sedimentary deposits of transported soils, by the me-

chanical action of the transporting water. It has been shown in a previous chapter that aggregates and wall bodies show a particular interior dynamic due to the continuous sequence of drying and wetting, and as a result of their dynamic, develop a particular fabric.

The effect of liming in diminishing the formation of "single grain structure" seems to be produced in the first place by neutralization of the soil solution, as a result of which binding substances unstable in acid soil solutions are stabilized. In addition, a new and more stable binding substance is introduced into the soil. In the chapter on soil fabrics it was shown that flocculation plays an important role in the establishment of elementary fabric types. It can be taken for granted, however, that it plays only a minor role in the formation of aggregates in agricultural soils. By complete flocculation of the binding substances, either no binding or the production of aggregates of inferior stability is observed.

Biological importance of spongy soil fabric. Soils having "crumb structure" cannot be considered as the best for crop production. As was mentioned above, loose soils, i. e., soils consisting of loose crumb complexes, are particularly subject to wind erosion which in most cases brings about severe damage to the growing plants. In fact, soils which by microscopic investigation show true "crumb structure" are mostly deposits laid down by the wind.

No other arrangement of the soil constituents can be superior to the spongy fabric produced by binding substances which offer a sufficient resistance against the destructive action of water and wind. Good aeration together with sufficiency of water permits a luxuriant development of important organisms such as fungi, actinomyces and aerobic bacteria. The spaces being sufficiently large in size allow the development and activity of soil insects, mites, springtails, nematodes, and other microscopic animals, as well as of large protozoa forms when the moisture content is high. They also permit the development of large fruiting bodies such as those of *Mucor, Rhizopus, Cunninghamella,* etc.

For the development of higher plants spongy fabric also provides the optimum conditions in the form of a high air content, and a great permeability and receptive capacity for rain water. In stable spongy fabric these well balanced conditions remain more or less undisturbed during the whole period of growth. The author believes that these favorable conditions are best

developed in certain types of chernozems represented by some Russian varieties which have a moderate lime content in the surface layer. An increase in lime content results in the separation of the coherent soil body into aggregates caused by the splitting effect of microscopic efflorescences and interflorescences of calcium carbonate in the surface layer, which are produced in the dry season, and increase the erodibility in spite of the originally perfect binding substances.

CHAPTER III

Observations on Humus Formation

Soil microscopy promises to be of particular help in the study of humus formation. The decomposition of the organic residues can be followed through all stages in the natural habitat to the formation of the various dark-colored substances resistant to decomposition. The organisms actually involved in the process can be isolated, their identity determined and the conditions under which the decomposition took place in the microscopic habitats studied in detail. Furthermore, the complexity of humus requires methods or research by which the constituents may be recognized as such and investigated individually and directly. Such methods consist of identification by optical properties, the differentiation by general microscopic appearance, and staining and microchemical reactions. In addition to direct investigation of the constituents, the numerous chemical preparations of humic substances can be tested in a similar way, and their identity or diversity determined by comparison with the natural humus components.

Humus, humic substances. By humus we understand the totality of organic residues resistant to decomposition in a given soil. The important criterion "resistant to decomposition" does not necessarily apply to substances which are entirely undecomposable. A certain difference in the degree of decomposability between different groups of substances is sufficient to permit the accumulation of one group and to cause the absence of the other. The nature of the substances accumulating in a given soil depends on the regional and local climate, the position, the water and air conditions, the acidity, the salt concentration and a number of other circumstances.

Substances rapidly decomposed in one soil may be left undecomposed and accumulated to a large degree in another soil. Thus, the hemicelluloses and celluloses rapidly decomposed in chernozems accumulate to a high degree in highmoor peat on account of its excessive water, low air content and high acidity. They are an essential part of the so-called white peat

(Weissmoortorf). In spite of the fact that the white peat consists for the most part of celluloses and hemicelluloses, and only for the least part of "humic substances," it is called "humus." It is a humus formation just as much as the raw humus layer of the podsols, the heat humus or the mor in forests.

By "humic substances" are understood the dark-colored brown to blackish, amorphous substances rich in carbon, which are difficult to decompose even under the most favorabe conditions and which, therefore, accumulate in the soil. Though their chemical constitution in the final stage of humus formation is but little known, they differ in appearance from the original substances in the bodies of plants and animals from which they are formed. Thus, "humic substances" is a term for typical compounds found in nature. "Humus" is a pedological term for a typical formation in nature.

The humic substances are of great importance in the morphology and genesis of soils and are highly characteristic for the different soil types. Extremely resistant to decomposition by microorganisms, they play an outstanding role in the fabric and dynamics of the soil. Every achievement which contributes to the knowledge of their composition, properties and behavior is, therefore, highly desirable from the standpoint of general pedology. Unfortunately, only little information is available to date, and the chemistry of the humic substances still represents one of the least successful branches of organic chemistry.

Particularly in the study of soil thin sections, humus and humic substances are found in characteristic appearance in the various soil types. Some of the differences, especially with regard to the humus substances, are brought out in the following descriptions.

Humic substances in humus podsols. While residues of higher plants with well preserved cell structures are found in the raw humus layer of humus podsols, the B-horizons show deposits of an entirely new dark brown to blackish substance. This substance is found dissolved in the acid soil solution and can be obtained by evaporation. It is found, furthermore, in the form of coatings around the mineral grains in the dried out soil, and is soluble to a great extent in slightly acid water. Other organic substances are almost entirely absent. Besides the humic substance the coatings contain free peptized aluminum and iron hydroxide. They are low, however, in the content of colloidal silica. This statement is important because the colloid in podsols was believed to be always as high in silica. The inor-

ganic colloids are found together with the humic substance as a more or less homogeneous mixture; they are easily separated by ignition. Thus, microscopic proof is given for the role of the particular humic substance in podsols (so-called "acid humus") as a protective colloid.

Humo-lignin. In addition to undecomposed celluloses, lignins, chitins, etc., the raw humus layer of podsols frequently shows a strikingly reddish to red-brown substance which was designated by K. Simon as humo-lignin. It is found in all places where lignified material is decomposed under moist and acid conditions, as a result of which the normal process of humification is disturbed. The reddish decay substances are, therefore, particularly characteristic of certain humus and soil formations. They are found often in rotten logs in forests with a podsol climate.

Humus substances of steppe and alkali soils. It was mentioned in the chapter on soil fabrics that in chernozems two types of humic substances are observed. One occurs in the form of insoluble blackish flakes of small scales and grains, the diameter of which varies around 3-10μ. The second type is peptized and brown-colored, and is observed in the form of very thin, transparent films around the mineral grains, in some cases visible only after staining. In thick layers and even with incident light it appears blackish. It can be seen in the form of accumulation crusts on the surface of aggregates and wall bodies. The peptized humic substance is insoluble in water and soluble in dilute alkaline solution. Substances of the same appearance are found in chestnut brown soils (where it is mostly accumulated in hardpan-like layers in the deeper parts of the humus horizon), in the brown and grey soils of the dry-steppe, and in preponderance in alkali soils. The peptized humus fraction generally is increased with the degree of alkalinity. In alkali soils it is extracted by pure water on account of the high base content of the soil. The evaporation residue is little affected by treatment with acetyl bromide. Since these peptized humic substances also differ from dark-colored lignins in their higher solubility in dilute alkaline solutions, they are evidently identical with the so-called "humic acids."

Thin sections of the soil types mentioned above clearly show the absence of hemicelluloses and celluloses, except in cases of easily recognizable fresh plant residues.

Melanin-like humic substances. It was mentioned previously (see page 209) that insect remnants are attacked mostly by

actinomyces followed by certain fungi, particularly species of *Mucor* and *Rhizopus*. By dissecting the accumulations of filaments the chitin residues of the insects show either blackish stains where the actinomyces have been attacking, or the residues as a whole are stained in a blackish-brown color. The phenomenon can be observed also with organisms isolated from soil onto artifical media high in protein, on which considerable quantities of deep brown melanin-like substances are produced. In soil the formation of the dark brown substances has been specifically observed in some ground water soils characterized by a high content of animal residues such as dried out water beds rich in zooplankton. If one considers that the single phenomena observed are repeated millions of times in a soil rich in animal remains, that the melanin-like substances are diffusable (as in the artificial medium) and therefore distributed throughout the soil, that they are highly resistant to decomposition and therefore accumulate, then one has at hand almost all the details for understanding the formation of the melanin group of humic substances in soil.

Alkaline muck humus. Some alkaline muck soils when prepared in the form of thin sections are excellent subjects in which to show a type of decomposition by which the anisotropic organic substances are removed, and the resistant isotropic substances (lignin, chitin, both with well preserved structures) are accumulated. A great abundance of diatom fragments is generally characteristic of this humus formation. In addition to the isotropic residues a great amount of very small blackish-brown debris-like humus particles are observed.

Humic substances in rendzina soils. It already has been mentioned in the paragraph on rendzina fabric that a blackish to dark brown, opaque humic substance is found in the form of crusts or protuberances on the surface of humus particles. Plant residues, much accumulated in the humus layer, show well preserved cell structures and are translucent, brown to reddish-brown, mostly isotropic, partly double refractive.

CHAPTER IV

The Soil Microflora and Fauna Observed by Direct Microscopy

1. INFLUENCE OF THE SOIL ON THE MORPHOLOGY OF THE MICROORGANISMS

DWARFED GROWTH

Many organisms occur in considerably smaller forms in the soil than in water or on artificial media. It is evident that the circumstance that they have to live in small spaces, and the great differences in nutrition are the principal causes for the phenomenon.

The Mucoraceae are particularly sensitive to the influence of the limited space in soils. According to observations of the author, the biggest fruiting bodies of *Mucor alternans* reached a diameter of 37μ in the soil (though in dried state), while on artificial media a size of 130μ is common. *Mucor glomerula,* showing sporangia of a diameter from 50 to 55μ, reached a diameter of 100 and 120μ on soil extract mannitol agar. The sporangiophores of the same fungus, showing a maximal length of 200μ in soil, reached a length of 900μ on artifical media. The differences in size are less evident with *Rhizopus nodosus* showing, in both cases, sporangium diameters between 80 and 140μ, though sporangia of about 225μ diameter have been observed on artificial media. The spores had an average length of 5μ in soils and of 7μ on artificial media. Considerable differences also were found with fungi imperfecti. The heads of the fruiting bodies of *Hyalopus crystallinus* had an average diameter of about 25μ in the soil and of 65μ on artificial media. The size of the conidia was about 3μ in soil and varied from 4 to 10μ on soil extract mannitol agar. The conidiophores in the soil had an average length of 60μ, and of 150μ on artificial media. Conidia of a *Cladosporium* reached a length of 9μ in the soil and of 17μ on artificial media.

Dwarfed growth, in the truest sense, is observed in protozoa in the soil, especially in the case of ciliates. Koffman (49)

found in his soils the largest ciliates were only 22μ in size. The author found individuals of *Colopoda steinii* of only 18μ (normally 30-60μ) in Austrian soils. In spite of these observations normal growth of ciliates can be observed wherever the conditions are favorable for their development.

Varieties of diatoms considerably smaller than those occurring in water are frequently observed in soil. One of the most frequent diatoms in soils, *Hantzschia amphioxys*, usually measures only a half or a third of the size of the aquatic varieties. The author has found individuals of 33μ length, the normal length being 60 - 150μ. As a rule, also a preferential selection of small species is observed, and a great number of species are not larger than the silt particles of the soil as, for example, *Navicula minima* (length 15μ), *Navicula pelliculosa* (10μ), *Navicula atomus* (5μ), and others. In spite of the fact that living diatoms as a rule are found only on the soil surface and rarely in the spaces of the interior soil the phenomenon of dwarfed growth and the preference for small species is doubtless also due to the limit in space. Normal soils are sufficiently permeable to keep only small and shallow water accumulations on the soil surface which are withheld by capillary tension.

PARTICULAR HABITS OF GROWTH

The differences in morphology of the same organism in soils and on artificial media may be so great that it becomes difficult to classify them under the same species or even the same genus. Thus, a *Mycogone* in a calcareous alluvial soil near Bruck, Lower Austria, was characterized by two-celled conidia of which the upper was globular and glassy clear and the lower half-globular or funnel-shaped and white. In culture on filter paper infiltrated with Wöltje solution the fungus showed unicellular conidia of the type of *Sepedonium*, while two-celled conidia occurred only sporadically (5). The conidia on the artificial medium occured frequently in bundles of four to five while in soil never more than two conidia have been observed on a side branch.

The well known variability of *Fusarium* frequently is observed also with species found in soil. Spores of Cephalosporium-like conidiophores frequently develop into normal *Fusarium* conidiophores on artificial media.

Fruiting bodies of *Gliocladium* usually appear in Hyalopus-like forms in the younger stages (fig. 124). A *Gliocladium* was

found by the author and C. E. Renn in the form of Acrostalagmus-like fruiting bodies in Sassafrass sandy loam without organic additions. After the addition of zein particles, conidiophores of Penicillium-type have been observed; the chains of conidia were joined in cream-colored compact masses which appeared frequently in cylinders of considerable length with plume-like, curled upped ends. On artificial media the fungus isolated from soil without additions as well as with the addition of zein, occurred in normal *Gliocladium* forms.

Sporangiophores of *Mucor glomerula* usually were found in dense clusters of a hundred or more growing on short, alternately or partly dichotomously branched, shrub-like sporangiophores on the surface of the space walls (fig. 125). The same organism, found as a parasite on *Rhizopus nodosus*, formed clusters of only 30 sporangia at most (fig. 121). The fungus transferred to filter paper impregnated with acid Wöltje solution developed such an amount of mycelium that the petri dish was completely filled by it. The sporangia were rarely found in clusters. In some cases long sympodially-branched sporangiophores were observed (fig. 127). The color of the sporangia was brownish as opposed to light-ochre in soils. On alkaline soil extract-mannitol agar, mycelium developed only in a thin veil-like layer. The sporangia were found mostly on alternate or partly verticillated branches of sporangiophores suspended on mycelium (fig. 126). In many cases a large sporangium (100 - 120μ) developed at the end of the stem. About 70 to 100μ below it five or more thin side branches originated from a slightly inflated spot in the stem, each bearing a much smaller sporangium (30-50μ). The columella of the main sporangium was cylindrical, that of the side-sporangia globular to half globular.

The *Cladosporium* in fig. 128 grew tree-shaped, Hormodendron-like in conidiophores in the soil, and developed Cladosporium-like conidophores on artificial media. The conidia were granulated and spiny in the soil, but entirely smooth in the culture.

Though the development of special soil forms is most evident and easy to observe in the case of fungi, it doubtless will be found also to apply to other soil organisms. Differences in the morphology of bacteria have been reported repeatedly. Great morphological differences have been observed in protozoa by M. Koffman by the application of his preparation method of microorganisms developed in soils (49).

2. THE GENERAL ASPECT OF THE MICROBIAL SOIL LIFE

A difficult part of direct soil microscopy always has been the observation of the bacterial life in the soil. It is easy to isolate drops of capillary water from habitats rich in bacteria, to examine them in transmitted light, to prepare them on slides (fig. 129) or to transfer them to artificial media in order to propagate the organisms contained in them. Even the preparation of soil crumbs or macerated organic residues taken from such habitats, or the transfer of these residues to artificial media in the form of suspensions, produces no difficulties. However, all these procedures represent more or less indirect methods carried out in the world of microscopic dimensions, and not direct methods of observation. The time when it will be possible to observe the soil bacteria *in vivo* and *in situ* in the soil and to work with them microtechnically just as is possible now with the larger organisms cannot be very far away. These possibilities are seen in the present stage of micrurgy and incident light microscopy. The author already has been able to obtain satisfactory pictures of undisturbed soil with a magnification of 900 times using his soil microscope in combination with the Epilum water immersion objective 60x with strong eyepieces. With this arrangement the smallest soil protozoa are easily visible and observable; it is probably only a problem of special dark field illumination or vital staining which keeps us from the final goal of seeing bacteria.

The best pictures of the bacterial life *in situ* are obtained at the present time by the Rossi-Cholodny technique. In many cases the buried slides show not only the authentic morphology and arrangement of the organisms, but also the organic residues or substances on which they are feeding. The Rossi-Cholodny method deserves a much greater application in soil microbiology than it has had up to the present time. Even preparations which show only sporadic growth of organisms may yield valuable information. Their examination should be carried out with more patience and more attention to detail than is customarily given to smear preparations from pure cultures. For soils with a thin bacterial population, the method suggested by Conn and further developed by Winogradsky (50), combined with the centrifuging of soil suspensions, is still of particular value. Since the natural arrangement of the organisms remains preserved in many cases in the form of zoogloea, accumulations of organisms in slime capsules together with small parts of soil, the preparation has the same relationship to the buried slides as

the debris preparation has to the thin section. Valuable information doubtless will be obtained also by the Koffman technique (51).

A welcome substitute for the investigation of bacteria *in situ* and *in vivo* is the soil chamber method as well as the soil dust method of N. Cholodny (52, 53) which at least allows an observation *in vivo* under conditions similar to those in soil. A modification of the soil chamber method wherein a natural soil space is covered with a cover slip and used as a soil chamber may find successful applications. Microscopic examination may be carried out either directly with incident light or after transferring the cover slip to a hollow slide where it can be examined with transmitted light.

The truth of S. Winogradsky's statement that most of the autochthonous bacteria (in the strict sense of the term) occur in coccus or oval forms can be seen in almost all soils low in bacterial life. It was confirmed also by J. Rossi's observation on his "glomeruli." The frequent occurence of rod-shaped bacteria on buried slides is due to the presence of plant, animal and microbial residues.

Bacteria are easily observed by direct microscopic examination if the formation of colonies takes place. This is noticed as a rule with iron bacteria (4).

The microtechnical method opens great possibilities for the observation of fungi, actinomyces and of the soil fauna. The appearance of fruiting bodies of various species of *Hyalopus* is typical for almost every soil under conditions of high moisture content (see water films in fig. 108). This "Hyalopus stage" of different soils, which can be observed in the field as well as in the soil cultures, almost can be considered an indicator of certain air and moisture conditions. Mycologists often have suggested dropping the genus *Hyalopus* and combining the forms which form slimy, globular conidial heads under high moisture conditions with the genus *Cephalosporium* the conidiophores of which bear dry conidia. However, in view of the significance of *Hyalopus* in soils, the author is in favor of keeping it as a separate genus since dry conidial heads of *Hyalopus* always indicate the end of the development of the fungus when conditions become unfavorable for its growth. On the other hand, there are different species of *Cephalosporium* which are typical in moderate moisture conditions in addition to other biological factors.

In some cases fungi may achieve such a luxurious growth

that almost all soil spaces are filled out with fungus hyphae, giving the impression that the soil body consists more of mycelium than of other soil parts. Observations of this kind, however, are seldom noted in agricultural soils, though the author, together with H. Wilson, found a fungus colony (probably *Trichoderma*) which extended over a circle of more than 25 feet in diameter and to a depth of 7 inches in Tama silt loam planted with corn. The fungus gave almost the whole soil layer an intense blue color.

Unique impressions are obtained by the observation of living diatoms and animals in their natural habitat. Because we customarily see them with transmitted light in the form of more or less two dimensional structures, it is a striking experience to see them bodily in soil in which they appear to us as something entirely new. The glassy, strongly reflective bodies of certain nematodes moving through the black-walled spaces of chernozem soils, or the sparkling crystal-like shells of diatoms slowly wandering over microscopic hills and valleys as if directed by a mind, is a surprising sight to anybody. A great diversity not only in shape, but also in colors, is shown by the algae on the soil surface, varying from the intense blue-green, olive, or verdigris of the *Cyanophyceae* to the yellow, ochre and brown of the diatoms, and the meadow green of the *Chlorophyceae*.

Although an abundance of protozoa, especially as far as large forms are concerned, is found only in a few particular soils, some habitats characterized by favorable water, food and space conditions may show a surprisingly luxuriant protozoan life. Nothing can be more fascinating than such habitats. They are almost always characterized by the presence of ciliates as the most active and predominant group. Though small individuals and small species as *Colpoda, Chilodon* and *Colpidium* are the most frequent (*Paramaecium* is rare in soil and has never been found by the writer), big ciliates may also be found; thus, representatives of certain *Hypotrichae* are typical in a number of soils. The best conditions for their development occur when spaces of higher order rich in plant or animal residues are entirely filled with water. By evaporation the water content is decreased, and the soil solution retires to side cracks, small worm holes and empty plant root channels. These water residues may become very crowded by the extremely active population of protozoa remaining (fig. 130). With great rapidity and surety they move along all bends and

corners of the channels until they are stopped at the ends at which their paths are closed by the surface meniscus of the water (fig. 131). Their behavior at the menisci is particularly interesting. Two or three times they would approach the barrier in rapid succession and then quickly turn around and pursue their way in an opposite direction. The author once had the occasion to observe a similar behavior in a short side channel of a water filled crack which led into a small round-shaped space. The animals which happened to penetrate into the side channel entered the round space and were stopped in their movement by the opposite wall. They would try several times and at different spots to run fiercely against the wall and then suddenly turn around and make their way back through the entrance. There was a stage in the development of certain *Hypotrichae* of the type of *Stylonynchia* at which they became very active in attacking other protozoa, which was not observed in earlier stages. Almost every other kind of protozoa was attacked, and also the some species. After the seizing of the animals, eager, jerky movements of swallowing have been noticed. The attacked animal could be carried along for considerable distances. However, only small individuals were really devoured, while the others were liberated after some time. Habitats containing great abundance of protozoa may be recognized in the dried stage by the numerous cysts (fig. 132) generally found on plant residues. In almost all cases it is possible to revive the protozoan life in the laboratory by the addition of water.

Some soils may have a great abundance of ciliates throughout all their parts. They are mostly sandy soils with wide intergranular spaces, rich in organic substances. It seems to be of particular importance that these soils are frequently and plentifully watered. Drying of the soil between the periods of the watering is not a disadvantage, but may even be favorable since the ciliates may be affected by some toxic substances produced in certain stages of the anaerobic decomposition of nitrogenous residues. Such soils having a high content of active ciliates are found most frequently in gardens, vegetable plots, artificially watered fields, flower pots, etc.

Rotatoria and Tardigrades likewise found under excessive moisture conditions are limited mostly to the soil surface or to spaces opening to the surface. Extremely numerous free living nematodes may be found in soils with spongy fabric. Their development is much increased in habitats in which easily

decomposable and particularly nitrogenous organic residues are found. Next to the nematodes, the mites are the most important representatives of the microscopic soil fauna. They are found in the air filled spaces of almost every soil where they can be observed feeding on plant remnants or fungus mycelium. Their excretions, mostly cylindrical in shape, may sometimes form a considerable part of the soil humus, particularly in forest soils. The springtails (Collembola) are an interesting group which are frequently found and evidently play the same role as the soil mites. In a few soils, species of *Chironomus* develop an extremely high activity. They lead to the numerous groups of highly active microscopic insects.

As a whole, direct microscopic examination enables an observation of the microflora and microfauna in their totality and makes detailed studies of their interrelations possible. The importance of the direct method is increased also by the fact that only a part of the soil microorganisms can be obtained by the plate method. These are mainly heterotrophic bacteria, fungi and actinomyces. Even among the latter organisms there are groups which grow in artificial media with difficulty, whereas, on the other hand, spores of certain fungi which are never found in the vegetative state in the interior of the soil easily produce cultures on artificial media. These limitations of the plate method are, of course, counterbalanced by other advantages so that both methods are complementary to each other.

In view of the potentialities of the direct microtechnical methods, the results obtained up to the present merely represent a beginning. The fact that a new method in research is found does not imply that the material which can be obtained with it can be reported after a few brief years of investigation. It will need at least a generation of detailed work just as was necessary for the development of the present soil microbiology by means of the culture methods.

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SUBJECT INDEX

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List of Errata for

MICROPEDOLOGY

by WALTER L. KUBIËNA

Page 34, line 7

"normal length of 1.60 mm" instead of "normal length, or 160 mm"

•

Page 84, line 16

"raised" instead of "lowered"

•

Page 106, horizontal column 6 (Beidellite)

"(Fe for Al)" instead of "(Fe for Cl)"

•

Page 106, horizontal column 7 (Nontronite)

$$\begin{cases} Si_4O_6 \\ Fe_4O_8(OH)_4 \\ \cdots\cdots \end{cases} \text{ instead of } \begin{cases} Si_4O_6 \\ Al_4O_8(OH)_4 \\ \cdots\cdots \end{cases}$$